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INSTRUMENTS

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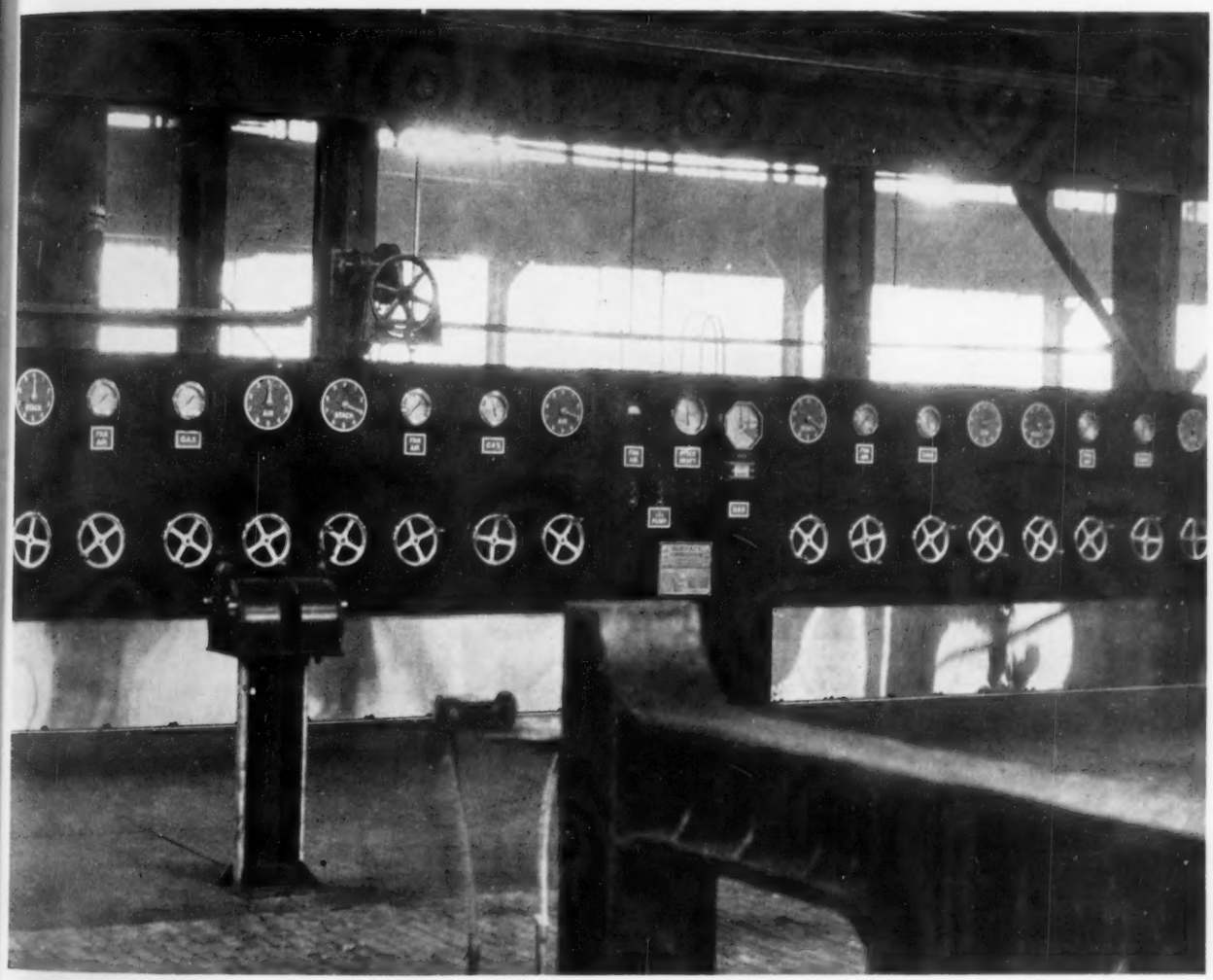
MEASUREMENT AND CONTROL

Volume 8 AUGUST 1935 Number 8



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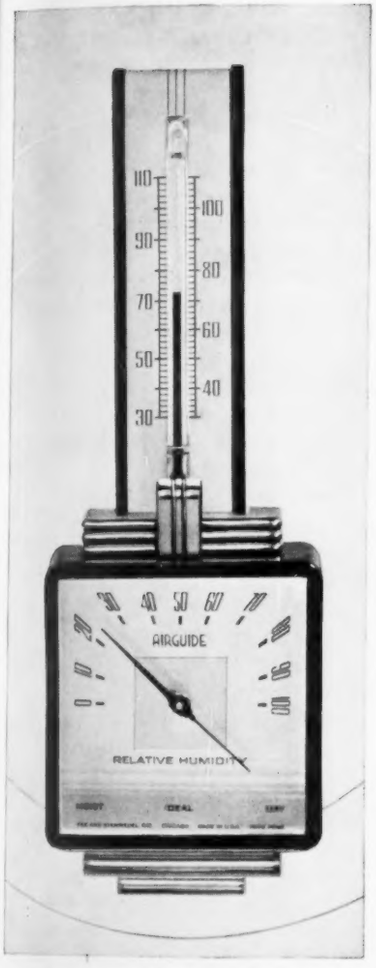

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THE TWO instruments shown here provide excellent examples of the versatility of Bakelite Molded. Both the designer and the manufacturer recognize that the rich color and lustre of this material will emphasize the beauty of the forms which they have created.

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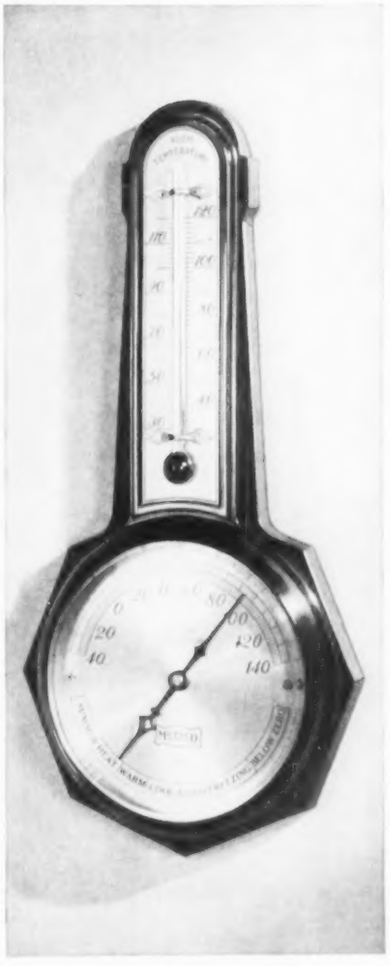
We invite instrument manufacturers to consult us about adapting Bakelite Materials to their individual needs, and also to write for our 48 page illustrated booklet 37M, "Bakelite Molded".



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INSTRUMENTS

THE MAGAZINE of MEASUREMENT and CONTROL

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EDITORIAL COMMENT

In This Issue

F. J. Leerburger "started something" when he alleged that most writers on fluid flow phenomena use a wrong Reynolds Number (*Instruments*, May 1934, page 89). Not only did authorities comment (July 1934, page 132) but we resolved to publish a full-length "last-word" article on nothing but *R*. We later modified this resolution in view of the excellence of the manuscripts submitted. Here at last is the result: a basic treatment by R. W. Keith, and an advanced discussion by Ed S. Smith, Jr.

Which, naturally, makes this issue the one in which to print the discussions of the famous Tuve & Sprenkle article on orifice discharge coefficients for viscous liquids. And what a galaxy of discussers!

Next, methods of slip measurement are discussed by Prof. E. W. Schilling and H. Williamson, and a new one described.

A series on electrical telemetering systems (part of the Borden & Béhar handbook) starts in this issue. It will include many exclusive first-time descriptions.

A useful cart for factory electrical tests, and what it does, are reported by William Barbour.

R. R. Batcher continues his Oscillography series with complete data on electrostatic deflection methods.

Lots of New Instruments!

And a whole library of Manufacturers' New Literature.

The front cover photograph shows the control board for the 4-hole Surface Combustion one-way fired soaking pits, fired with natural gas, at the Allegheny Steel Co., Brackenridge, Pa. The complete operation of the pits is controlled from this board. Draft, fuel and combustion air are controlled by means of the hand wheels. Damper position is shown by the indicator immediately above the hand wheels, and gages indicate the amount of gas and fan air on each hole. The master panel in the center indicates and records the amount of fan air used by the entire battery. It also is equipped with an Askania automatic draft regulator commanding the main stack damper. Above the board is shown a hand winch permitting hand operation of the main stack damper.

The Inspection and Testing title-page photograph shows (artistically!) how resistance of a finish to impact is measured at "Bell Labs" by slowly turning a coated panel and subjecting it to successively harder blows by a steel ball.

Motion and Time Study and Instrumentation

PROPERLY applied by industrial engineers, motion and time studies benefit employer and employee. Costs are reduced, wage rates increased and comfort factors ameliorated. Yet in many industries "the man with the stop watch" suffers the hate of labor and the scorn of management. The *man*—seldom the stop watch; never the impersonal automatic time recorder.

Your editor has for years invited rotten-egg showers by lecturing industrial engineers on the need of "applying time-study procedure to time-study procedures" in order to determine the One Best Way for one man to analyze the tasks of others; on the need of developing a new branch of Instrumentation combining applications of psychology with the use of stop-watches and of specialized time recorders; on the need of training time study men to make the utmost use of present instruments, so that even more refined instruments can be developed, calling for even greater skill.

Beside a variety of modern stop-watches (each valuable in its way) there are available numerous forms of automatic running-and-idle time recorders. These already have proved their worth on vehicles, on machines that vibrate, and where the opening and closing of circuits is made to correspond with time elements to be recorded. There are also printing type time recorders from the simplest office model to the marvelous "Chronolog." There is the micromotion camera which sees all, times all, cannot lie and pays for itself on standardized all-year jobs. There is the recording wattmeter, whose charts so often point out the "better way." (In fact, *every* type of recorder can serve as a time-operation recorder.)

At this point of our sermon we are usually told that these recorders were not developed for making "man-and-machine process charts"; that *no* recorders have been or are likely to be developed for this specific purpose. That is not so: several years ago, beginnings were made in Germany by Dr. Poppelreuter (with his three-pen, spring-motor chart-drive "Time Analyst" which the time study man carries by a shoulder strap, his hands free to press the pen buttons and to write quick symbols on the moving chart) and here by the General Electric Co. (with its semi-portable electrically-operated eight-pen "Time Analyzer"). A few months ago, Adelbert Ford, Professor of Psychology in Lehigh University and time-study adviser to textile mills, designed a "featherweight" time recorder with five keys arranged to fit the pattern of a man's right-hand finger tips, producing five parallel records on a tape chart. This recorder can be operated effortlessly and (with practice) unconsciously. It represents the triple alliance we have been preaching—psychology plus industrial engineering plus Instrumentation—in the War on Waste; and we are happy to announce that Prof. Ford has written an article for *Instruments* which will be published as soon as his instrument (now in the shop) can be photographed.

In our opinion this is only a beginning. The time-study man of the future will have been *trained* to operate *twenty-pen* or *hundred-pen* instruments producing analytical records of *all* that he sees when observing a task. Such records will constitute better "man-and-machine process charts" than are now made so laboriously without adequate Instrumentation. We have been told that such skill is unattainable. To which we answer: "What about playing the 84-key piano and the multi-keyboard-and-pedal grand organ?" There the argument rests. What do *you* think?

M. F. Behar

TWO ARTICLES PRESENTING COMPLEMENTAL REMARKS ON **R** *BY TWO INVESTIGATORS OF FLUID FLOW PHENOMENA*

How the Reynolds Number Originated and How to Compute Its Value

By RAFAEL W. KEITH*

OSBORNE REYNOLDS, the creator of the "Number" which bears his name, was the very personification of the well-rounded research mind. In addition to his work in fluid flow, he tackled innumerable other problems, and his technical papers cover fields that range from the development of means of keeping sewer gas out of houses to rather abstract dissertations on the ultimate nature of things.

Previous to Reynolds it had been discovered that the loss in head of a fluid flowing in a given pipe obeyed two different laws. Briefly stated these laws are:

When the velocity is low, loss in head is proportional to: $\frac{l\mu v}{d^2\rho}$ .....(I)

When the velocity is high, loss in head is proportional to: $\frac{lv^2}{d}$ .....(II)

Now, this jump from one law to another—this finite discontinuity of mother nature—is precisely the sort of thing that sets research minds going. When Reynolds got loose on the problem, he developed a hunch to the effect that if the two foregoing laws were equated, some general criterion of fluid flow would result. On performing the suggested operation, the result was

$$\frac{dv\rho}{\mu}$$

which expression is none other than R, the Reynolds Number !

Now, it remained to be shown that R was really a criterion of fluid flow. In this connection much experimental work was done by Reynolds[1] himself and later by Stanton and Pannell.[2] The data from many other experimenters have been correlated by Kemler,[3] and more recently Van der Pyl[4] has given us (through *Instruments*) a summary of the latest data on the subject. In all these papers, definite values of the friction coefficient f for use in the Darcy formula for loss in head

$$\Delta h = f \cdot \frac{l}{d} \cdot \frac{v^2}{2g} \quad \text{.....(III)}$$

are given in the form of charts of f plotted against R. The finding of reliable values of f has therefore been boiled down to the calculation of the numerical value of the Reynolds Number, and the subsequent graphical conversion of R into f.

Most writers on fluid flow have stated that if a consistent system of units is used, the Reynolds Number will be dimensionless, and will therefore have the same numerical value regardless of the system of units used. Unfortunately, most writers on fluid flow do not say what they mean by a "consistent" system; consequently, confusion has occurred in the choice of units. In the rest of this paper, the writer will attempt to clarify this situation.

Any given system of units is ordinarily based on three fundamental and purely arbitrary conventions. From these conventions derived units are obtained; thus for example, if the distance between two scratches in a metal bar is taken as the basic unit of length, then area is (length)^2 and volume is (length)^3. Similarly, if a fraction of the mean day is taken as the basic unit of time, then velocity is (length)/(time) and acceleration is (length)/(time)^2.

On the choice of the third basic unit of the system there are two possibilities: either it is a unit of *mass* or else it is a unit of *force*. The difference is fundamental. A unit of mass is a definite portion of matter that has been arbitrarily chosen to be such a unit. When it is said that a body has unit mass, it is meant that if this body is placed in one pan of a balance, and the unit of mass in the other pan, then perfect counterpoising will take place (vacuum assumed).

On the other hand, a unit of force is a standard of push or pull. It is conceivably possible to frame a standard for force that is not associated or dependent on an arbitrary portion of mass. For example, it may be said that the basic unit of force in a system is the attraction between two specified surfaces, in vacuo, at a unit distance apart, one of which surfaces has been previously

NOTATION

d = diameter of the pipe. (See Table I for units)
l = length of the pipe (Same units as d)
v = average velocity of flow. (Table I)
ρ = density of the fluid flowing (Table I)
μ = absolute viscosity of the fluid flowing. (Table I)
Δh = loss in head of the fluid flowing. (expressed as a difference in elevation. Same units as used for d and l)
f = friction coefficient. A dimensionless constant numerically equal to the fraction of the velocity head lost for each diameter length of pipe.
g = acceleration that a freely falling body acquires due to the attraction of the earth. Its numerical value in any consistent system of units is the same as the force with which the earth attracts a unit of mass of the system.

*Ithaca, N. Y.

charged with electricity by rubbing in a specified manner with cat's fur.

Now, if the basic units of a system are length, *mass*, and time, then force can be expressed in terms of the basic units, and in this case, force is a derived unit. Likewise, if the basic units are length, *force*, and time, then mass is a derived unit.

POSTULATES

In order that a given system of units be dynamically consistent, two conditions must be fulfilled:

(1) The density of a substance must be expressed as the ratio of mass to unit volume; or in other words: (mass)/(length)^3.

(2) The unit of force in the system must be defined on the basis of the push required to give a unit of acceleration to a unit of mass of the system. Mathematically this condition is expressed as follows:

$$\text{(force)} = \text{(mass)(acceleration)}$$
$$= \text{(mass)(length)}/\text{(time)}^2$$

As a practical example, consider the Absolute English System; also called at times the "Gravitational System." Here the unit of length is the foot. The unit of mass is a chunk of matter called the pound. The unit of time is the second.

To be dynamically consistent, density is pounds per cubic foot; and force is in (pounds) (feet)/(second)^2. A push or pull of one (pound) (foot)/(second)^2 is called by the British a "poundal" and for purposes of visualization it may be added that such a push or pull is closely 1/32.2 of the force with which the earth attracts a pound of mass. (32.1740 is the standard.)

Consider next the American Engineers' System. Here the foot is used for the basic unit of length, and the second for the basic unit of time. When dealing with forces, everyone is accustomed to use the pull with which the earth attracts the standard pound as the basic unit of force. Now, to be dynamically consistent, the unit of mass must then be of such proportions as to acquire a unit of acceleration when acted upon by a force of one pound. Such a chunk of matter is called a "slug" and also a "geepound" (Ref. 6, page 73). For purposes of visualization, it may be added that one slug of mass weighs close to 32.2 pounds, or about a third of the weight of an ordinary bag of Portland cement.

In this paper the basic units of the American Engineers' System are considered to be: feet for length, slugs for mass, and seconds for time.†

Now, in order to be dynamically consistent, density must be expressed as slugs per cubic foot, and force is then a derived unit which in terms of the basic units becomes: (slugs) (feet)/(second)^2. In other words, a pull of one (slug) (foot)/(second)^2 is the same as the pull with which the earth attracts the standard pound.

In the Metric c.g.s. System, the basic units for length, mass and time, are respectively centimeters, grams and seconds. The unit of force is called the dyne, and this in terms of the basic units is expressed as (grams) (centimeters)/(second)^2. For purposes of visualization it need only be remembered that a force of one dyne is equal to 1/980 of the force with which the earth attracts a mass of one gram. The numerical factor is 1/980 instead of 1/32.2 because 980 centimeters represent the same length as 32.2 feet.

†If one should want to consider the basic units of the American Engineers' System to be: feet for length, pounds for force, and seconds for time, then mass is a derived unit expressed dimensionally as (lbs. force) (sec.)^2/(ft.). Density must then be expressed as (lbs. force) (sec.)^2/(ft.)^4. Numerically it is the same to say that a substance has a density of one (lb. force) (sec.)^2/(ft.)^4 as to say that it has a density of one slug per cubic foot. An interesting discussion on the question of "force" versus "mass" as a basic unit is contained in Ref. 20.

When substituting actual numerical values in the expression for the Reynolds Number, the term "absolute viscosity" is encountered. We can now consider how this property of matter is expressed in terms of the basic units.

By definition, the *absolute viscosity* of a fluid is the force required to pull a plate of unit area at a unit velocity, parallel to and at a unit distance from a large plate, the space between both plates being full of the fluid. As

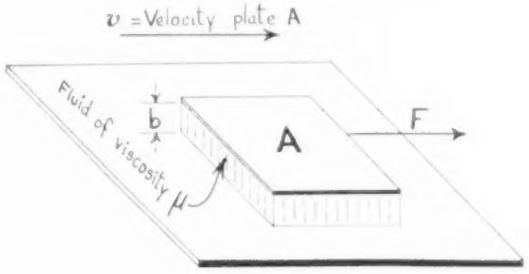

Fig. 1

can be seen, absolute viscosity is a measure of the shearing resistance of a fluid. This definition is illustrated by Fig. 1, from which it is easy to infer that force F depends directly on the area of the plate A, on the velocity v, and on the absolute viscosity μ of the fluid; also that force F depends inversely on the distance b between the plates. Therefore, absolute viscosity can be defined mathematically, by an equation:

$$\mu = \frac{Fb}{Av}$$

As to the units of absolute viscosity, consider for example the Absolute English System. Using poundals for force, square feet for area, feet per second for velocity, and feet for the distance between the plates, the resultant units are found to be poundals-second per square foot. Similarly, in the American System, using pounds for force, the resultant units are: pounds-second per square foot. And in the Metric c.g.s. System the units are: dynes-second per square centimeter.

In general, the units of absolute viscosity as obtained from the definition are in the form: force-time per unit area. Now, we are dealing with systems of units whose basic units are length, *mass*, and time; therefore, force is a derived unit, and in order to express viscosity exclusively in terms of the fundamental units it is necessary to use the second postulate for consistency.

In the Absolute English System, one poundal represents the same pull as one pound-foot per second squared. In the American System, one pound of force represents the same pull as one slug-foot per second squared. In the Metric c.g.s. System one dyne is the same as one gram-centimeter per second squared.

When force is expressed in terms of basic units and the result is substituted in the previously found dimensional equation for absolute viscosity it is found that in the English System, the units of absolute viscosity are: pounds per feet-second. In the American System: slugs per feet-second. In the c.g.s. grams per centimeter-second. In other words, when absolute viscosity is expressed exclusively in terms of the basic units, it is in the form of: mass per length-time.

It can now be shown that any system of units meeting the two initial postulates will give a dimensionless Reynolds number:

TABLE I—SUMMARY OF CONSISTENT UNITS

Name of System	Basic Units			Dimensional equivalents of "force"	Consistent units for dimensionless Reynolds Number $\frac{dv\rho}{\mu}$			
	Mass	Length	Time		Absolute viscosity $= \frac{Fb}{Av} = \mu$	Diameter d	Velocity v	Density ρ
Absolute English	pounds	feet	seconds	poundal $= \frac{\text{pound-foot}}{(\text{second})^2}$	$\frac{\text{poundals-second}}{(\text{feet})^2} = \frac{\text{pounds}}{\text{feet-second}}$	feet	$\frac{\text{feet}}{\text{second}}$	$\frac{\text{pounds}}{(\text{feet})^3}$
American Engineer's	slugs	feet	seconds	pound $= \frac{\text{slug-foot}}{(\text{second})^2}$	$\frac{\text{pounds-second}}{(\text{feet})^2} = \frac{\text{slugs}}{\text{feet-second}}$	feet	$\frac{\text{feet}}{\text{second}}$	$\frac{\text{slugs}}{(\text{feet})^3}$
Metric C. G. S.	grams	cm.	seconds	dyne $= \frac{\text{g.-cm.}}{(\text{second})^2}$	$\frac{\text{dynes-second}}{(\text{cm.})^2} = \frac{\text{grams}}{\text{cm.-second}} = \text{Poises} = \frac{\text{Centipoises}}{100}$	cm.	$\frac{\text{cm.}}{\text{second}}$	$\frac{\text{grams}}{(\text{cm.})^3}$
German Engineer's	kilograms	meters	hours	$\frac{\text{kg.-meter}}{(\text{hour})^2}$	$\frac{\text{kilograms}}{\text{meter-hour}}$	meters	$\frac{\text{meters}}{\text{hour}}$	$\frac{\text{kilograms}}{(\text{meter})^3}$

A poundal is 1/32.2 of the force with which the earth attracts a mass of one pound.
A slug may be defined as the mass of 32.2 standard pounds.
A dyne is 1/980 of the force with which the earth attracts a mass of one gram.
A German kg.-meter/(hour)^2 is $1/127.4 \times 10^6$ of the force with which the earth attracts a mass of one kg.

$$R = \frac{dv\rho}{\mu} = \frac{(\text{diameter})\ (\text{velocity})\ (\text{density})}{(\text{absolute viscosity})}$$

$$= \frac{(\text{length})\left(\frac{\text{length}}{\text{time}}\right)\left(\frac{(\text{mass})}{(\text{length})^3}\right)}{\frac{(\text{mass})}{(\text{length})\ (\text{time})}} = 1$$

The discussion has so far taken up what philosophers would call the epistemological aspect of the problem. That is, we have considered the origin, source, and validity of the units that should be substituted in the expression for the Reynolds number. But engineers are interested less in philosophy than in quick ways of achieving results. For this reason, two tables have been prepared, which it is hoped will be of value to those interested in fluid metering. Table I gives a summary of the units now in use. They have been arranged in consistent groups and are ready for immediate use. Table II gives some of the more current reduction factors.

The Reynolds number must be based on absolute viscosity as defined previously (Fig. 1). Sometimes, however, viscosity is expressed in other ways, as for example: (1) relative viscosity, (2) kinematic viscosity, (3) Saybolt viscosity. It is of course important to be able to reduce these viscosities to absolute viscosity.

(1) *Relative viscosity* is the ratio of the absolute viscosity of the fluid to the absolute viscosity of water under a previously agreed condition of temperature. Relative viscosity is therefore a dimensionless magnitude that has the same numerical value regardless of the system of units used. One must, however, be careful in knowing just what is the temperature of the water that is taken as a standard. In this country, Daugherty[5] and others use 20°C. or 68°F. as the standard. At this temperature the absolute viscosity of water expressed in centipoises** is close to unity (Ref. 7); and therefore, in this case, relative viscosity is the same numerically as absolute viscosity in centipoises. On the other hand, Ref. 8 gives tables of relative viscosity which are based on water at 0°C. or 32°F. According to Ref. 7 the absolute viscosity of water at this temperature is 1.7921 centipoises. For this case, relative viscosity is numerically equal to centipoises divided by 1.7921.

(2) *Kinematic viscosity,* by definition, is the ratio of absolute viscosity to the density of the fluid under the same conditions of temperature. In general, the units of kinematic viscosity are length squared per unit time. Inasmuch as both the English and American systems use feet for length and seconds for time, the units and numerical value are the same in both systems. If kinematic viscosity is designated by the symbol y, then the Reynolds number becomes: dv/y
which also is dimensionless since by definition $y = \mu/\rho$.

(Continued on page 205)

TABLE II—CONVERSION FACTORS

Given—	multiply by—	result—
A force in pounds	32.2	A force in poundals.
	444,000.	A force in dynes.
	57,700,000.	A force in kg-meter/(hour)^2
A mass in pounds	0.0311	A mass in slugs.
	0.454	A mass in kilograms.
	454.	A mass in grams.
A length in feet	30.5	A length in centimeters.
	0.305	A length in meters.
A density in lbs./cu. ft.	0.0311	A density in slugs/cu. ft.
	0.0160	A density in grams/cu. cm.
	16.0	A density in kilograms/cu.m.
An absolute viscosity in poises—dyne-second per square centimeter or grams per cm.-sec.	100.	An absolute viscosity in centipoises.
	0.0672	An absolute viscosity in the Absolute English system poundal-sec./sq. ft. or pounds/feet-sec.
	0.00209	An absolute viscosity in the American Engineer's system. (Not used in practice) pounds-sec./sq. ft. or slugs/feet-sec.
	360.	An absolute viscosity in the German Engineer's system kilograms/meter-hour.

**A centipoise is one hundredth of a poise. Poise is the name for the unit of absolute viscosity in the Metric c.g.s. System. In terms of the basic units, one poise equals one gram per centimeter-second.

Alternative Forms of the Reynolds Number

By ED S. SMITH, JR.*

UNQUESTIONABLY, the Reynolds number in the form vd/ν should be retained in publications as the standard basis for correlating data on flow meter coefficients, for ease of comparison with the mass of accessible data already so published.

Alternative forms, especially those involving only known values, are more convenient in applying coefficients when using a manometer or recorder showing the differential pressure P as head of the manometric liquid (or in inches of water) or as the square root of this differential uncorrected for coefficient changes. (It generally is impracticable to measure the differential pressure P by the head H of the flowing fluid itself.)

Starting with the Reynolds number

$$v\frac{d}{\nu} \qquad (1)$$

these alternative operators are, progressively, since the coefficient C is a function of the Reynolds number,

$$C\sqrt{2gH}\,\frac{d}{\nu} \qquad (2)$$

$$C\sqrt{\frac{P}{\rho}}\cdot\frac{d}{\nu} \qquad (3)$$

and

$$C^2\frac{P}{\rho}\left(\frac{d}{\nu}\right)^2 \qquad (4)$$

or, omitting the to-be-determined coefficient C,

$$\frac{P}{\rho}\left(\frac{d}{\nu}\right)^2 \qquad (5)$$

and for square-root recorders

$$\sqrt{\frac{P}{\rho}}\cdot\frac{d}{\nu} \qquad (6)$$

Again, from (5),

$$\frac{P}{\rho}\left(\frac{pd}{\mu}\right)^2 \qquad (7)$$

$$P\rho\left(\frac{d}{\mu}\right)^2 \qquad (8)$$

or, for square-root recorders,

$$C\sqrt{P\rho}\,\frac{d}{\mu} \qquad (9)$$

or

$$\sqrt{P\rho}\,\frac{d}{\mu} \qquad (10)$$

By 1923, there had already been considerable use in the oil industry of

$$Q/d\nu \qquad (11)$$

where Q (gallons/minute) = volume-rate of flow,
d (inches) = diameter of pipe, and
ν (cm²/sec) = kinematic viscosity.

Oil venturi meter coefficients were plotted on this basis by the writer in his 1923 A.S.M.E. paper.[1] The kinematic viscosity ν is most conveniently used for liquids since it is found directly from the viscosimeter reading in Saybolt seconds. The kinematic viscosity ν of a liquid does not change appreciably with ordinary pressure changes, and generally varies with temperature in a well-known manner.

In Appendix V of his 1925 I.C.E. paper[2] John L. Hodgson gives "The Relation Between the Viscosity-Effect and the Other Factors Affecting Flow" as follows:

". . . it can be shown that for liquid flows general results for any particular value of the diameter ratio can be expressed by plotting the relation between the coefficient and

$$P\rho\,(d/\mu)^2 \ldots" \qquad (8)$$

In the commercial metering of steam and gases, some use has been justly made of

$$W\,d\mu \qquad (12)$$

where W is the mass-rate of flow. The customary use of the volume-rate under standard conditions with gases is merely another way of stating the mass-rate of flow. The absolute viscosity μ is most convenient to use with gases since it changes inappreciably with pressure and slightly, in a known manner, with temperature.

In the 1930 Foxboro book "Flow Meter Engineering" (page 160), Leland K. Spink, in discussing gas meters, states that "Provided flowing temperature and roughness of pipe remain constant, viscosity deviations from the flow formula on each ratio of orifice to pipe diameter may be plotted against

$$C\sqrt{P\rho}(d/\mu) \qquad (9)$$

or any function thereof."

In his 1932 *Forschung* paper on the flow of gases through orifices,[3] Nusselt used Odquist's operators as a basis for coefficients. The writer, in discussing Nusselt's paper, pointed out[4] that the use of Odquist's operators was not rational from a physical standpoint. In his closure[4] Nusselt proposed, for liquids, the replacement of the Reynolds number by

$$\sqrt{P\rho}(d/\mu) \qquad (10)$$

In 1934, A. Hollander plotted nozzle coefficients for acceptance tests of centrifugal pumps for liquids[5] upon substantially this same basis (10) that uses only known numbers.

A discussion of the effect of omitting the coefficient from its plotting basis occurs in the writer's recent A.S.M.E. paper[6] on "The V-Notch Weir for Hot Water," which presents an alternative form of Reynolds number suitable for use with weirs. This form was made practical only by the omission of the coefficient from its plotting basis.

Similarly, for graduating gaseous fluid meters, the expansion factor Y may conveniently be plotted against a function of the quantity-rate instead of the acoustic ratio: $(P/P_1)/k$, where P/P_1 is the ratio of differential to total pressure and k is the specific heat ratio.

The safest procedure is to publish all data on the standard Reynolds number basis using the inlet conditions unless otherwise specified. Then it is a simple matter for any reader familiar with the subject to convert these values into the forms (5) and (6), using the kinematic viscosity ν, for liquids, or forms (8) and (10), using the absolute viscosity μ, for gases. When the reader is not well enough acquainted with these conversions to make them readily, it seems to the writer that confusion must result from the reader's attempts to reconcile data from various sources correlated upon different forms. Although the writer has made informal use of these alternative forms since 1923, and often found them convenient, still he is increasingly convinced that the general use of a single, standard form of the Reynolds number is most desirable in all publications of flow meter coefficients.

*Hydraulic Engineer, Builders Iron Foundry, Providence, R. I.

[1] Ed S. Smith, Jr. The Oil Venturi Meter. Paper No. 1889. *ASME Transactions*, Vol. 45, 1923, pages 67-75.

[2] John L. Hodgson. The Orifice as a Basis of Flow-Measurement. The Institution of Civil Engineers. *Selected Engineering Paper* No. 31 (Published without discussion), 1925, 23 pages.

[3] W. Nusselt (Original paper). Die Stroemung von Gasen durch Blenden. *V.D.I. Forschung, Ausgabe B*, Vol. 3, Jan.-Feb. 1932, pages 11-20.

[4] Ed S. Smith, Jr. Discussion of above paper and Closure by Nusselt. *V.D.I. Forschung, Ausgabe B*, Vol. 4, Jan.-Feb. 1933, page 38.

[5] A. Hollander. Open Flow Orifices for Pump Acceptance Tests. Bulletin of the Byron Jackson Pump Co., 1934.

[6] Ed S. Smith, Jr. The V-Notch Weir for Hot Water (RP-56-9). *ASME Transactions*, Vol. 56, October 1934, pages 787-789.

Orifice Coefficients for Viscous Liquids

DISCUSSIONS

of Article by G. L. TUVE and R. E. SPRENKLE in *Instruments*, November 1933, pages 201-206.

AUTHORS' CLOSURE will appear in next issue.

By ED S. SMITH, JR.*

AN artistic and useful correlation of data has been made in graphical form by the authors. The writer herein presents** a formula that may prove useful in providing a mathematical expression of the same data. A brief discussion of the state of the art of metering flow with orifices is also presented, as is another covering the practical use of meters and their correction factors.

FORMULA

The viscosity correction for orifices at Reynolds numbers (R_2) of 100 to 10,000 closely follows a skewed probability curve, *i.e.*, one having tilted ordinates, when plotted against this Reynolds number on log-log paper, and consequently may be empirically expressed as follows:

$$y = a/\log^{-1}(bx^n) \qquad (1)$$

and

$$y = \log C - \log C_0 \qquad (2)$$

where

y = viscosity correction (log) of coefficient
C = coefficient
C_0 = coefficient approached at high Reynolds numbers
d_2 = orifice diameter
d^1 = pipe diameter
R_2 = Reynolds number (log) based on conditions at d_2
R_0 = base Reynolds number (log) corresponding with skewed ordinate passing through maximum coefficient, axis of symmetry
x = departure (log) of skewed ordinate from R_0

For $d_2/d_1 \leq 0.5$, the ordinate need not be skewed for sufficient accuracy and so

$$R_2 = R_0 + x \qquad (3)$$

for $d_2/d_1 > 0.5$,

$$R_2 = R_0 + x + 2y \qquad (4)$$

where 2 = coefficient slope at low Reynolds numbers, and a, b, n are constants depending on the "shape" d_2/d_1

*Hydraulic Engineer of Builders Iron Foundry, Providence, R. I.
**Presented at the session of the A.S.M.E. Special Research Committee on Fluid Meters during the 1933 Annual A.S.M.E. Meeting.

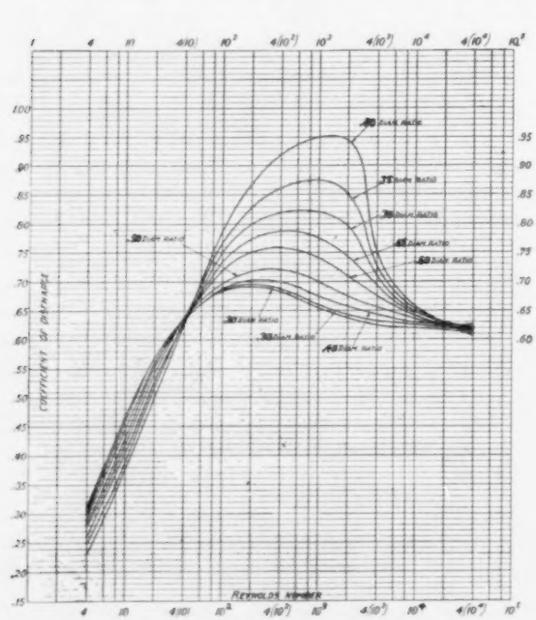

Fig. 1 of Tuve & Sprenkle article (greatly reduced).

From Fig. 1 of the Tuve-Sprenkle article, the following illustrative values are tabulated:

d_2/d_1	0.2	0.5	0.7
a	0.0500	0.0783	0.1172
b	0.432	0.286	0.409
n	2.00	1.65	2.80
$\log R_0$	2.25	2.52	2.58
$\log C_0 + 1$	0.7890	0.7803	0.7987
C_0	0.6152	0.6030	0.6286

By plotting these, or similar, values against d_2/d_1 a useful correlation of data from various sources may be obtained. No effort has been made to adjust the above tabulated values, the last column of which is shown on the writer's Fig. 1A. The smaller ratio orifices show even less departure than for this 0.7 ratio.

By a proper selection of the constants, the formula may be made to fit the curve exactly at a number of points as follows: The axis of symmetry is first found by bisecting the space between the two points on the curve at a given ordinate, the value of C_0 is next taken near the value at the higher Reynolds numbers on the graph (this is not exactly the same as the value approached at an infinite value of the Reynolds number). The intersection of the skewed axis of symmetry with the base coefficient C_0 gives the value of R_0 and also of constant a. Where x is unity, the value of constant b is determined. Then taking x equal to one-half, the value of constant n is found. A weighted value may be obtained by similarly computing n at $x = 1.5$ or some other value. Thus the skewed probability curve of the formula will agree exactly with the data curve at four, or more, points, resulting in an exceptionally low probable error with this formula.

Calculations with this formula are simple and straightforward, requiring the use of only the familiar slide-rule and 5-place logarithm table without interpolation to obtain values with an error of $< 1\%$, which at present appears to be less than the experimental error. Although the writer prefers graphical methods in using coefficient data, still the above formula may be useful in the preparation of such graphs and tables.

At Reynolds numbers lower than 100, the coefficient falls away from the probability curve and approaches a straight line on log-log paper having the same slope as the angle to which the ordinate has been skewed in the above treatment. Hence, the writer's formula should not be used below Reynolds numbers of 100.

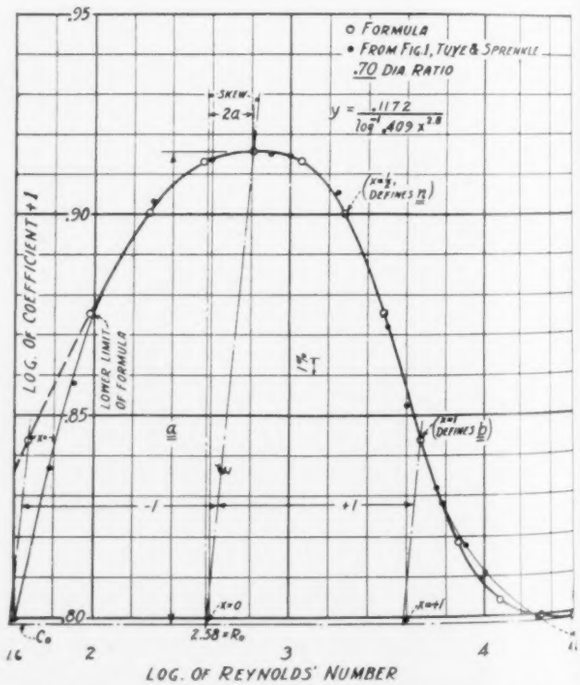

FIG. 1A. EXAMPLE OF USE OF FORMULA $y = a/\log^{-1} bx^n$

At higher Reynolds numbers, with rough pipes, the coefficient becomes flat at a value that may, or may not, agree with that of the base coefficient C_0 of the formula. If it agrees, then the formula may fit the data fairly closely. More data are needed for this region than were presented in the paper discussed. However, such data are probably now available, or soon will be.

With smooth pipes at the higher Reynolds numbers, the values of y, on the above basis, may be plotted on semi-log paper against the corresponding values of x and found to be a straight line for a given diameter ratio. The writer recommends that the skewed probability curve be used up to $x = 1$ and that the above semi-log basis be used for all higher values of the Reynolds number. This method avoids any appreciable inaccuracy in joining data from other sources with those of the paper under discussion.

With smooth pipes at very high Reynolds numbers, Dr. Buckingham observed that the coefficient may be plotted against the reciprocal of the Reynolds number to give a practically straight line. This has the obvious advantages of simplicity and some physical meaning, since the effects of viscosity are compared directly with the viscosity that now appears in the numerator of the abscissa. However, the line is strongly curved in the region covered by Tuve's and Sprenkle's article. For that region, the formula proposed by the writer appears to be the more useful.

The skewed probability curve formula has been presented by the writer as a first step toward a more comprehensive solution. He discussed it in its formative stages with Drs. Buckingham and Young and their stimulating interest is gratefully acknowledged. Although a tilted, damped harmonic curve fits the data better at Reynolds numbers below 100, the formula presented above is easier to use and gives higher accuracy at the more commonly used, higher Reynolds numbers. Incidentally, in regard to Fig. 1, the coefficient lines on the semi-log paper used in Fig. 1 should be curved instead of straight at very low Reynolds numbers, which they would be on log-log paper.[2, 7]

CORRECTION FOR KINEMATIC VISCOSITY

For metering oils, it is convenient to use the kinematic viscosity since this is readily obtained from the usual viscosimeter time and also avoids the inevitable question as to whether mass or force units are involved. The kinematic viscosity of water at 68°F. (20°C.) is 0.010 cm.^{2}/sec., or, dividing by 929 (the number of square centimeters in a square foot) is 0.0000108 ft.^{2}/sec.

In one form or another, the Reynolds number remains the best operator for the correlation of coefficient data. However, for use with commercial meters, the correction is most simply plotted on a graph based upon the Reynolds number using the *indicated*, instead of the actual, rate. This practical method is correct and involves only known quantities. The accompanying Fig. 5A shows such a graph having the same purpose as that of Fig. 5 of the article being discussed. Fig. 5A is suitable for use with a Chronoflo, or other, orifice meter having a cam that corrects for the coefficient variation at the various rates within the range of the meter at the kinematic viscosity normally existing in service.

While it admittedly requires extra expense in calibrating, or graduating, such a meter at the factory, still the meter requires no correction at the various rates used under ordinary conditions. Further it will be noted that practically the same amount of correction is required at the various operating rates for any given temperature, with its accompanying kinematic viscosity—except for the lowest of the rates. Even at the lowest rate, the correction is but a fraction of that for the meter of Fig. 5 that is graduated to have a true square-root cam. Herschel Standard Venturi Tubes used with registers having special cams correcting for coefficient variation with rate have proved accurate on pipe line service with crude oils requiring up to 10% viscosity correction. 1932 and 1933 routine operation tests on such meters show, based on tank gagings:

Average agreement within	0.58%
" (algebraic) agreement within	0.07%
Max. individual disagreement	1.96%
Min. " "	0.006%

also, acceptance tests averaged within several tenths of one percent. The above standard Venturi tubes have shown excellent performance in extended use on oils containing paraffin.

Combined density and coefficient corrections are not generally safe to make up, on account of the likelihood of error. The writer greatly prefers, as the result of more than fifteen years' experience in metering viscous fluids with both Venturi and orifice meters, to use entirely separate graphs for density and coefficient corrections, since the coefficient varies

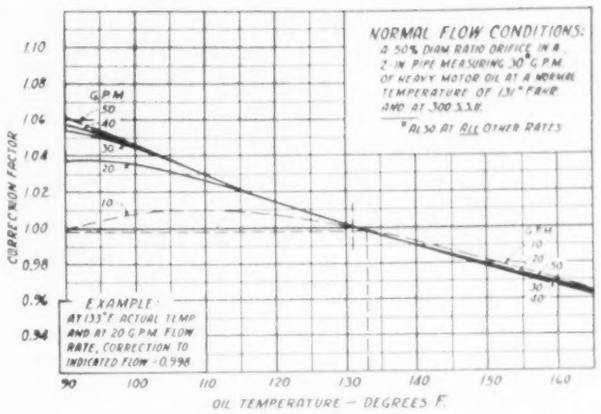

FIG. 5A. EXAMPLE OF CORRECTION FACTORS FOR VISCOSITY, DENSITY AND INDICATED FLOW RATE.

with different ratios. Also, the correction for density is applied in one way where the flow rate is in gallons per minute and in another where it is in pounds per hour. It is definitely unsafe to rely on combined graphs such as Figs. 5 and 5A, since mistakes are certain to occur over a period of time.

GENERAL

It might appear from a casual reading of the article being discussed that Tuve and Sprenkle were the first to establish that orifice coefficients may be related to the Reynolds number. That this is not a correct impression may be established by reading the appended references relating to this rapidly developing art. The contribution of the article discussed is in the direction of obtaining a slightly greater accuracy than was previously obtainable from the tests of Hodgson, Daugherty, Witte and others, or rather in making more certain that the data from such divergent sources, and upon somewhat different designs, applies to the orifices now in commercial use in this country.

Straightening vanes should be used with all flow meters at Reynolds numbers of less than 4,000 on account of the relatively non-uniform velocity distribution there.

The fundamental idea of "correspondence" has not always been understood alike by various workers in this field. The coefficient may be said "to be related with" or "to correspond with" the Reynolds number in both the viscous and turbulent flow régimes, and even where the coefficient is "flat" at high Reynolds numbers. It does not mean that the coefficient must necessarily "vary with" the Reynolds number, but merely that it can be plotted against the Reynolds number and have a single value of the coefficient for each value of the Reynolds number. Interesting use has been made of this basic principle by the writer in obtaining operators for correlating expansion factors of gas orifice meters and viscosity factors with weirs for hot water and light oils.[2, 7, 10]

The writer offers the new formula only as a stop-gap, in the hope that its publication will stimulate others to work out a more comprehensive formula.

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[2]1923: Ed S. Smith, Jr. The Oil Venturi Meter. *Transactions A.S.M.E.*, Vol. 45, paper No. 1889, pages 67-75.

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[6]1926: Robert L. Daugherty. A Further Investigation of the Performance of Centrifugal Pumps when Pumping Oils. *Bull. 130*, Goulds Pumps,, Inc.

[7]1929: Ed S. Smith, Jr. Quantity-Rate Fluid Meters. *Transactions A.S.M.E.*, HYD-52-7b pages 89-109.; and also "Venturi Meters and Controllers for the Oil Industry," *Bull. 244*, Builders Iron Foundry.

[8]1930: Leland K. Spink. Principles and Practice of Flow Meter Engineering (Book). The Foxboro Company.

[9]1932: W. Nusselt. Die Stroemung von Gasen durch Blenden. *V. D. I. Forschung, Ausgabe B*, Bd. 3, pages 11-20, Bd. 4, page 38, Heft 1. Discussion by the present writer showing that Nusselt's use of Odquist's substitute was incorrect. Closure by Nusselt proposing similar form to that of Spink above, but omitting coefficient. Hodgson had similarly omitted the coefficient in his 1925 I.C.E. Paper No. 31, cited above.

[10]1934: Ed S. Smith, Jr. The V-Notch Weir for Hot Water (and Light Oils). *Transactions, A.S.M.E.* Vol. 56, No. 10. Paper RP-56-10, pages 787-789.

By W. H. CARSON* and H. J. EVANS†

THE School of Mechanical Engineering, University of Oklahoma, is cooperating with the research sub-committee of the American Society of Mechanical Engineers in investigating the characteristics of fluid flow for viscous liquids. While the test work has actually begun, there are not enough data available to be used in a comparative manner. The first test runs are being made on a section of 4" pipe. A comparison of the coefficients with the different Reynolds numbers for this size line, and the sizes used by the authors of the article, would be extremely interesting.

There certainly can be no question about the accuracy of the results given in the article, since the various test runs were repeated and like data obtained. There are some points that might be cleared up through discussion about the set-up of apparatus and methods of obtaining data. In Fig. 2, an orifice flange with vena contracta and corner connections is shown. The method of drilling through the flange would not be satisfactory, for in most cases there would be leakage through the threads. For this type of connection it would be necessary to use a filler. The objectionable part of the filler is that there is a possibility of the joint not being flush with the remainder of the test section. This objectionable feature could be eliminated by careful manufacturing and doweling as shown. For the corner connections the annular space method would seem to be more advisable as an average differential pressure would be obtained.

There is one point that we have brought up on several occasions when corner connections are used, and that is, that since other connections are arranged geometrically, depending on the pipe size, we believe that the thickness of the orifice plate at the gasket contact points should be some percentage of the pipe diameter. This should make the differential pressure readings taken across orifices in the different-sized lines proportional. In most set-ups great care is taken to eliminate the roughness factor in the test section by using brass tubing both upstream and downstream. Then, to make a scientific investigation, a series of holes are drilled through the test section. It is our belief that this will have some effect on the accuracy of readings since the fluid passing through the orifice has a circular motion and at the point of vena contracta the fluid that is not in the direct line of flow is moving spirally.

The straightening vanes used were placed about 100 diameters from the orifice; this is a much greater distance than is recommended in commercial practice. We are of opinion that if the vanes had been placed closer to the orifice, the turbulent action would not have been as great and the value of coefficient would be different. We are wondering if the authors are planning to recommend the use of straightening vanes in commercial installations.

The same method was used for changing the viscosity of oil as we plan to use here, that is, by heating. The exact temperature range was not mentioned in the article. This is hardly necessary, however, since the change in orifice area is only about 0.5% for each 150°F. change in temperature.

No mention has been made as to whether a separating fluid was used in the manometers. With an open-end manometer this would hardly be necessary if the U tube was absolutely uniform throughout its length. The mercury level above zero could easily be read on the open end. There is one possible error in this case, however, and that is, would the oil recede when the differential decreased or would it fill in part of the space occupied by the mercury?

With the set-up here at the University of Oklahoma we do not plan to weigh the oil during the run. Two 100-barrel tanks placed one above the other have been installed so that when conditions have become constant we can instantly shift the flow of oil from one tank to another through the use of air-actuated valves. At the end of a certain period the flow will be diverted to the other tank. The oil will then be leisurely weighed.

From the curves that have been submitted by the authors it is plainly shown that the use of the Reynolds numbers is not altogether satisfactory. The method of obtaining coefficients as shown in Fig. 3 is to a certain extent a "cut and try" proposition. This would be satisfactory in small installations such as where oil is to be used for processing purposes and the approximate quantity would be known. However, in pipe line use where the quantity varies, it would be necessary to use an average coefficient for Reynolds numbers between 100 and 40,000. For Reynolds numbers about 40,000 the coefficient seems to be independent on the Reynolds number. If it were not for the disadvantage due to impractical pipe and orifice diameters it would be advisable to operate under conditions giving the higher Reynolds numbers. The curves on Fig. 1 certainly show that something is happening in the region where Reynolds numbers are around 2,000. This is undoubtedly, as the authors have stated, the region in which a change in type of flow is taking place.

The article shows the results of an admirable piece of work and we are sure that those of us who are pioneering in such tests will be greatly benefited through the results obtained.

*Director, School of Mechanical Engineering, University of Oklahoma, Norman, Okla.

†Graduate student in the School of Mechanical Engineering, University of Oklahoma, Norman, Okla.

By RONALD B. SMITH*

THE authors are to be congratulated on their efforts to interpolate their tests with the data of other investigators. It remains now for the profession to utilize their composite curves by an intelligent application of the principles of similarity.

Unfortunately no single criterion of similarity exists. For instance, the Reynolds number is a measure of dynamic similarity, but purely dimensional reasoning shows that unless geometric similarity is satisfied as well, the standard coefficients cannot be used with surety. Since orifices for the viscous region frequently mean small physical dimensions as well as viscous fluids, the problem of exact geometric proportion is most difficult. In fact it is undoubtedly the crux of the whole question of tolerance.

For extremely thin orifices the flatness of the orifice plate is a problem of considerable importance in this connection and one that is probably not realized generally. Although not strictly applicable Kerchoff's[1,2] analytical treatment of a sharp-edged slit offers a quantitative estimate of the seriousness of this feature. The analysis shows that the path of a fluid particle leaving the sharp corner of a slit in flat wall (present writer's Fig. 1) is defined in polar coördinates by the functions

$$x = \frac{2b}{\pi}(1 - \cos\theta) \tag{1}$$

$$y = \frac{2b}{\pi}\left[\sin\theta - \ln\tan\left(\frac{\pi}{4} + \frac{\theta}{2}\right)\right] \tag{2}$$

with the boundary condition that the width of the aperture is equal to $(\pi + 2)\ 2b/\pi$. Equation (2) approaches asymptotically the value $2b/\pi$, and gives the well-known relation for the flow coefficient

$$C = \frac{\pi}{\pi + 2} = 0.611$$

The character of the functions represented by (1) remain unaltered if a converging mouth of any length but of exactly the same profile as the free fluid path is added to the slit. Thus assuming that due to mechanical imperfections or to elastic deformations the plate is no longer flat, but is curved in the manner shown in Fig. 2, it follows from (1) that the new value of the flow coefficient may be represented by

$$C^* = \frac{\pi}{\pi + 2\cos\theta} \tag{3}$$

*Turbine Engineering Dep't, Westinghouse Electric & Mfg. Co., South Philadelphia Works.

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[2]H. W. Swift. Calibration of an Orifice. *Philosophical Magazine*, Series 7, Vol. 8, Oct. 1929, pages 409-435.

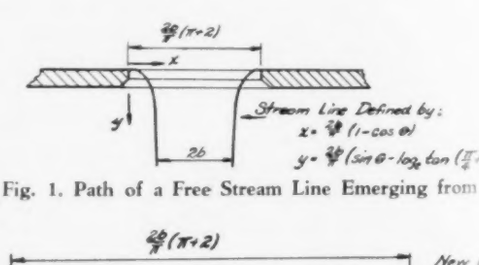

Fig. 1. Path of a Free Stream Line Emerging from a Slit.

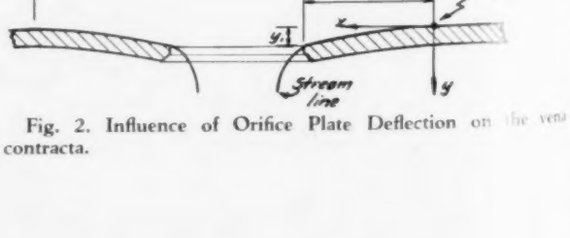

Fig. 2. Influence of Orifice Plate Deflection on the vena contracta.

where θ is the angular position corresponding to the coordinates x and y which locate the edge of the slit. The change in coefficient ΔC is represented by

$$\Delta C = \frac{C^* - C}{C} = \frac{2(1 - \cos\theta)}{\pi + 2\cos\theta}$$

$$= \frac{2x}{\pi + 2\cos\theta}$$

Assuming that the relations will not be markedly different for a circular orifice, we find for a 3/8" diameter:

θ	x/1	y/1	C
12°	0.0016	0.00023	+ 0.862%
10°	0.00112	0.00014	+ 0.59 %

For a small diaphragm it appears that a deviation of 0.0002" from a true flatness may increase the flow coefficient by as much as 0.75%.

Deflections of this extent are not unknown in very thin diaphragms. For instance, a hydrostatic pressure difference of only 2 lbs./in.^{2} produces an elastic deflection of 0.0002" at the inner edge of a 3/8" brass orifice plate, 1/32" thick in a pipe of 1¼" inside diameter. Thus the problem may become of genuine importance, particularly in view of the fact that these proportions are about the same as used by Tuve and Sprenkle.

While rigid adherence to this analysis does not exist inasmuch as the static deflection curve is not identical with the functions of equation (1), some effect will undoubtedly be apparent in diaphragms as thin as those tested. Perhaps the authors' systematically high coefficients (in Fig. 7 of their article) for small diameter ratios may be explained on this basis. Certainly tests with thicker diaphragms, but in other respects geometrically similar, would be of interest.

By C. E. LUCKE*

IN general, it is good to see coefficients referred to the Reynolds number as the prime variable to bring such data in line with other types of data on flow that vary with the rate of flow and physical properties of the fluid.

It would be more orthodox to designate the three flow zones as laminar, unstable, and turbulent, instead of viscous, critical and turbulent. Also in dealing with each quantity including the Reynolds number a dimensionless ratio it is best practice to keep all quantities in absolute units of any convenient system, e.g.s. or ft. poundal, second, when analyzing phenomena, even though in the case of the Reynolds number the numerical value is the same for any consistent system of units. This enables direct comparison with other scientific results most of which are reported in absolute units. When the work is finished a final working form for engineering results may then be obtained by a single application of conversion factors.

The upper and lower critical values of the Reynolds number between which the unstable zone of flow rate lies, are best defined and identified by the relation of loss of pressure to Reynolds number, or the ratio of the loss of pressure to the velocity pressure $pv^2/2$ in absolute, or $pv^2/2g$ in gravitational units. This ratio is the flow resistance coefficient and from the data of these tests it is possible to plot it with reference to the Reynolds number, and this should be done. In the three flow zones, the curve should be different but one should merge into the other as for Stanton curves of skin friction coefficients. When such a plot is made, other data on resistance coefficients can be spotted on the same sheet to check consistency. Inci-

Continued on Page 225

*Consulting Engineer, Babcock & Wilcox Co., New York City.

ORIGIN and COMPUTATION of the REYNOLDS NUMBER

—*Continued from page 200*

If the Metric c.g.s. System is to be used consistently, then kinematic viscosity must be expressed as the ratio of absolute viscosity in poises (or grams per cm.-sec.) to density in grams per cubic centimeter. In portions of the literature (Refs. 5, 19) kinematic viscosity is given as the ratio of centipoise viscosity to density in grams per cubic centimeter. This is done because its value is close to unity for water at 68°F.

(3) *Saybolt viscosity.* In a large portion of the literature, viscosities are given in Saybolt seconds. This is a purely arbitrary means of expressing viscosity. The apparatus used in the measurement consists of a can with a short tube at the bottom. In operation, the time in seconds required for 60 cubic centimeters of the liquid to flow out is reported as the Saybolt viscosity. Since the rate of flow depends on both the absolute viscosity and the pressure head, and since pressure head is a function of the density of the fluid, Saybolt viscosity is a function of kinematic viscosity.

For the new Saybolt viscometer, Herschel[16] gives:

$$\text{Kinematic viscosity} = \frac{\text{poises}}{\text{grams/cc.}} = 0.0022 \times t - \frac{1.8}{t}$$

where t is the viscosity in Saybolt seconds.

If viscosity is given in degrees Engler (German), Redwood seconds (English), or in Barbey fluidity, then other methods of reduction must be used. Information on these matters can be found in Refs. 9, 14, 18.

Ordinarily, numerical values of absolute viscosities are more readily available in metric units than in English units. Because of this, some writers advocate the use of a mixture of English and metric in the expression for the Reynolds number. The numerical value that is obtained for R is of course different from what would be obtained if consistent units were used exclusively. The R used in plotting the charts of Refs. 5 and 19 has been calculated from the following choice of units: d = inches, v = feet/sec., ρ = grams/cc., μ = centipoises. To obtain the consistent value R from this hybrid R, multiply the latter by 7750. It seems that considerable confusion would be avoided if writers having a fancy for hybrid varieties of R would also include on their charts a scale of values of R as calculated by the use of consistent units.

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A Slip or Differential-speed Indicator

By E. W. SCHILLING* and H. WILLIAMSON†

FOR measuring small differences in speed—as for example that between synchronous and full-load speed of an induction motor—various schemes can be used. Probably the most common method of measuring induction motor slip is by means of a stroboscopic disk and a neon lamp. This particular method is worth while as a means of illustrating the principle of the stroboscope but is not satisfactory for the accurate measurement of slip at loads much beyond 50% of rated value.

Another method, not quite so well known but much better, makes use of a differential gear system and a revolution counter,[1] one end of the differential being driven by a small synchronous motor and the other by the machine whose slip is to be measured. This second method gives the average value of slip for the period of time covered by the count. (In the case of a brake test the average slip may differ from the slip corresponding to a certain load.)

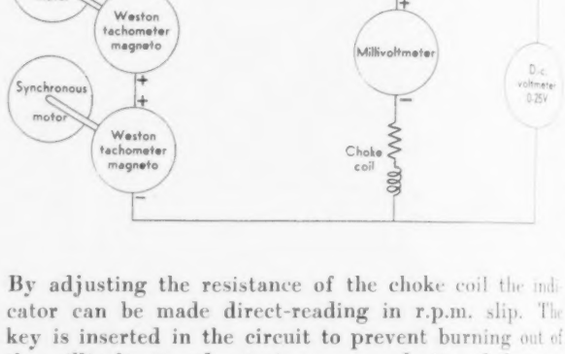
A device consisting of a commutator having the same number of segments as the motor has poles[2] and connected through a resistance to one phase of the power supply and to a d.-c. ammeter has been used. If the motor whose slip is to be measured runs at synchronous speed the impulses of current measured by the ammeter would always be at the same point on the alternating e.m.f. wave, and the reading would be constant. When the rotor speed is less than that of the synchronous field the impulses occur at different values of the current and the needle swings at the frequency of the currents in the rotor circuit. The slip is found by counting the swings per minute. Frequently a polarized bell is used in place of the ammeter. This method has the disadvantage that it is difficult to count the swings for high values of slip. The rubber tip of the device is often pressed against the shaft instead of using a positive connection. This may introduce a large error due to imperfect contact.

Two of the methods already described have been objectionable because of difficulty of counting at high values of slip. A device[3] which makes it possible to read high values of slip as easily and accurately as the lower values makes use of a hardened conical drum directly connected to the motor being tested. A wheel making contact with the drum is mounted on a screw carriage which is parallel to the face of the drum. By turning a small hand crank the wheel can be moved along the surface of the drum. When the wheel makes contact at the point where the diameter of the drum is equal to that of the wheel it will run at the same speed as the drum and motor shaft. Attached to the wheel shaft is a small stroboscopic disk having the same number of white sectors as the motor has poles. A neon lamp is used with it in the usual manner. It is not necessary to do any counting: the speed of the disk is adjusted by turning the hand wheel until the disk appears to stand still. The slip is then read directly off a scale parallel to the carriage. This provides a highly accurate method of measuring slip, but is fairly expensive to construct—requiring fine workmanship—and the friction drive between the drum and wheel may introduce an error. (Slippage is reduced by using a wheel making a line contact, and the contact is maintained by means of a light spring.)

The method of measuring slip to be described has the following advantages:

(1) It gives instantaneous values of slip.
(2) No revolutions to count; less opportunity for error.
(3) Many plant, commercial and college laboratories have all the necessary equipment for assembling it.
(4) Practically no equipment is tied up permanently prohibiting its use for other purposes.

The direct-reading slip meter uses two Weston tachometer magnetos and an ordinary millivoltmeter having a 0-50 range. The schematic diagram of the circuit is shown in the figure. One magneto is driven by a synchronous motor and the other by the motor being tested. Their voltages are balanced against each other at synchronous speed. Any difference in speed will cause a current to flow, giving a reading on the millivoltmeter.



By adjusting the resistance of the choke coil the indicator can be made direct-reading in r.p.m. slip. The key is inserted in the circuit to prevent burning out of the millivoltmeter due to improper polarity of the magnetos. The 25-volt voltmeter should read zero when the two magnetos are running at the same speed. A reading on the voltmeter indicates that the polarity of the magnetos is reversed. The choke coil is for the purpose of introducing damping into the millivoltmeter circuit.

The key, voltmeter, choke coil, and six binding posts are permanently mounted on a 6″x12″ oak board. All permanent wiring is done on the bottom of the board. Before and after each test the instrument is checked by driving both magnetos off the common shaft of a 1/10 h.-p. synchronous motor.

The results are highly satisfactory. Readings are obtained with extreme rapidity and the utmost of ease.

*Associate Professor of Electrical Engineering, Michigan College of Mining and Technology, Houghton, Mich.
†Former student, Michigan M. & T.

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Telemetering and Totalizing*

By PERRY A. BORDEN† and M. F. BEHAR**

1. The Essentials of Telemetering Systems.

The branch of Electrical Instrumentation to be treated in these articles may be described briefly as indicating, recording or integrating electrical or non-electrical magnitudes "at a distance by electrical translating means"—to quote from the A.I.E.E.-A.S.A. Report on Proposed American Standard Definitions of Electrical Terms. Telemetering is much more than that, however. Liberally interpreted, the wording quoted would admit practically all electrical instruments, whether the meaning of "translating" be "converting" or "transmitting" or even both.

Example, a thermoelectric pyrometer wherein temperature is converted into electromotive force and wherein electricity is used to indicate or record at a distance—wherein, therefore, temperature is indicated or recorded at a distance by electrical translating means.

There follows in the Report a somewhat tighter definition,

Telemeter. A telemeter is the complete measuring, transmitting and receiving apparatus for indicating, recording or integrating at a distance by electrical translating means . . .

which lays down an additional stipulation, namely, that an apparatus and not a relatively simple instrument is denoted. In view of the importance of electrical telemetering in every modernized industry, there is more at issue than a quibble over words. This definition should be interpreted with utmost strictness by engineers concerned with equipment specifications. An essential feature of telemetering, as distinguished from mere measurement at a distance, is suggested by the order of the words "measuring, transmitting and receiving." It is proper, we believe, to read into it an implicit stipulation that the apparatus must perform the functions of (1) measuring, (2) transmitting and (3) receiving, *separately and in the order given.*

What distinguishes telemetering (whether electrical or other) from mere measurement at a distance is *conversion at the point of measurement*—the conversion of an *already measured* magnitude into one which is readily transmittable.

If it were not so, we would have to include any ordinary switchboard frequency meter (which of course is capable of indicating in Chicago the frequency of an a-c. generator in New York if connected therewith); or a radio-frequency meter (which can indicate the frequency of a station at the antipodes).

The conversion must be performed in the transmitting apparatus of the system—at the point of measurement. The transmitter proper does not perform a measuring function. Its dual function is to (1) convert the result of an antecedent measurement into a "message" which can readily be sent and (2) send this message.

We must also consider "*completeness.*" The dictionary definition,

Telemeter . . . [2] An instrument to transmit variations marked by some physical instrument.

properly excludes pyrometers, resistance thermometers, pH meters, and other electrical instruments included in a too-liberal interpretation of the A.S.A. definition. It also has the advantage of applying to non-electrical branches of Instrumentation, but it presumably is restricted to the combination of a transmitter, receiver and line, excluding the "physical instrument" (measuring element). Without such an element, a telemetering system would be incom-

*Sixteenth chapter (XLIV) of Part Seven (Handbook of Industrial Electrical Measurements and Control) of Béhar's *Manual of Instrumentation*. See editorial announcement of this series on page A7 of November 1933 *Instruments*. Each chapter is subjected to a final revision shortly before its appearance in this serial form, in order to assure that the subject matter is thoroughly up-to-date. This new book is not published serially in any other periodical. Entire contents copyright. To be issued in book form on or about Jan. 1, 1936.

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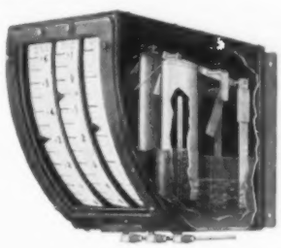

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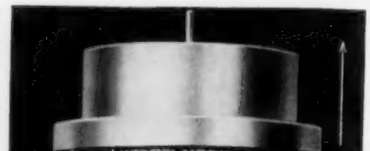

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plete because the scale or integrator dials of its receiver would be blank, and because it would be inoperative anyway.

"At a distance." Telemetering is not necessary for measuring frequency at great distances. Similarly, instruments bearing no resemblance to telemetering systems are employed to measure the spectral wave-lengths and the temperatures of remote stars. What is meant by "at a distance" is that a telemetering system can transmit the measurement of a particular condition or property to a greater distance than is practicable with the types of instruments generally or preferably employed for measuring this particular condition or property.

Further remarks on the A.I.E.E.-A.S.A. definitions:

1. The general field of Instrumentation is not limited to electrical measurements and control; and telemetering as a branch thereof is not limited to the application of electrical systems. There are hydraulic systems (as on board ships) which fall within the strictest definition of "telemetering" if such definition does not stipulate electrical transmission. In this treatment, of course, we deal only with electrical telemetering.

2. "Telemetering system" is preferable to "telemeter" because (1) it connotes the separate performance of measuring, transmitting and receiving, and because (2) the word "telemeter" has meant for centuries (in most modern languages including English) a surveying instrument or military range finder for the measurement of distance. Today it also means an apparatus for measurement *at a* distance, but the accepted meaning of "telemetry" is the measurement *of* distance.

Connection between transmitter and receiver. It is probable that majority opinion still considers a *tangible* line (all-metallic or including ground) to be an essential of telemetering; but the authors favor the inclusion of systems employing Hertzian waves as the transmitting channel. The use of radio signals for incrementally advancing a pointer, a pen-arm or a register has already passed beyond the experimental stage. Two recent systems (though now employing tangible channels as placed on the market) were originally invented for "telemetering by radio." In a few years, *televising* the images of indicator dials, of recorder charts and of integrator indexes will no longer be a novelty in the field of industrial telemetering.

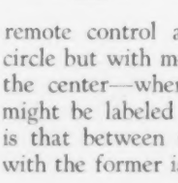
All these considerations lead to a definition:

Telemetering is the indicating, recording or integrating of a measured magnitude, at a distance greater than otherwise practicable, by means of a system including (1) *a measuring element at the point of measurement,* (2) *an element associated therewith converting the measured magnitude into a more readily transmittable magnitude or effect of proportionate value,* (3) *a receiving indicator, recorder, integrator or combination instrument,* (4) *a connection between* (2) *and* (3).

These articles cover only electrical telemetering systems in which the *transmitted* magnitude or effect is electrical. The *measured* magnitudes include not only those of an electrical nature, but also temperature, pressure, liquid level, speed, flow, illumination, angular deflection, as well as any physical or chemical property whose variations can be converted into changes in the value of an electrical magnitude. Whereas a decade ago there were but a few known methods (and these for the most part more or less "hand-tailored"), there are today at least sixty different electrical systems on the American industrial market. Thus the ramifications of the subject are almost unlimited—as will be brought out in the next section:

2. Summation, Demand and Supervisory Control.

The essential elements of many telemetering systems on the market, with slight modifications and in certain cases with none at all, can be adapted to various elaborate uses, such as adding and transmitting the results of several independent measurements, or even to a function which is not telemetering at all: the *operation at a distance* or "command" of substation equipment and other classes of apparatus. Conversely, there are on the market numerous electro-mechanical systems, each of which was designed for the performance of some such function, none of which is called a telemetering system, but which closely resemble telemetering systems. We may liken the present state of the art to four fields: 1) telemetering, 2) totalizing, 3) remote control and 4) supervisory control—forming four quadrants of a circle but with more or less vague boundaries between them, especially toward the center—where lies an amorphous "commons" of indefinite area which might be labeled "electrical remote-instrumentation." The vaguest boundary is that between telemetering and totalizing: nearly every reader concerned with the former is interested in the latter, because in the majority of industries



the introduction of "simple" telemetering systems is followed by eager requests for totalizing electrical energy or the flow of fluids. Hence the title and scope of this treatment.

Totalizing being closely associated with telemetering, the possibility that totalizing may be required at some future date should be a controlling factor in the choice of a system. Such a possibility would not need to be considered when a temperature telemetering system, for instance, is being specified; but even a single system for fluid flow or for electrical energy is quite likely to be required to form part of a subsequent totalization.

In the telemetering of electric current or power, the determination of *demand* sometimes becomes the dominant factor, in which case it often is found that telemetering systems having an inherently slow response show a distinct advantage over those aiming at instantaneous action.

Inseparably associated with telemetering, too, is the more recent practice of *supervisory control,* which refers generally to the combination of (1) the command of apparatus such as generators, turbines and circuit breakers from a distance, with (2) indications or records of conditions at the controlled end of the system. This field of remote control is beyond the scope of this work; and the practice of supervisory control cannot here be touched upon except insofar as may be necessary to make clear the principles of some telemetering systems.

3. Elements and General Characteristics.

A telemetering system may generally be considered as being in three distinct sections: the measuring-and-transmitting assembly, the receiving instrument, and the interconnecting line. The cost of the line may be said to vary directly with the distance to be spanned; the costs of the transmitting and receiving apparatus seldom depend on the length of the line; therefore the selection of relatively expensive terminal apparatus often minimizes the total cost of an installation. By the same token it frequently pays to share the line between a telemetering and a communication system, such as telephone or telegraph; while in other instances it is found practicable to operate two or more telemetering systems over a common circuit. The problem of reducing the number of interconnecting conductors in relation to the number of independent functions effected over the circuit belongs properly to the field of communication engineering; and for details the reader is referred to works on that subject. In this study the systems will be considered for the most part as though the connecting circuit were devoted exclusively to telemetering.

A general statement (which, however, has many exceptions) is that the devices at the receiving end of a telemetering system are more likely to be subject to continual personal supervision than the apparatus at the transmitting end, and hence this apparatus should be as simple as possible, any essential complications being transferred, so far as practicable, to the receiving end.

In many installations a supply of electrical power for operating the system is available at only one point—more likely the receiving than the transmitting station. Thus, the applicability of a certain system to a specific problem may depend on the possibility of operating it with power supplied at the receiving end only.

In the transmitting section of a system the transmitter proper is associated with a measuring element but the two are distinct. In some telemetering systems they are separable: the transmitter can be associated one day with an element which measures water level, and the next day with an element which measures illumination (requiring of course a corresponding change at the receiving end from one scale marking to another). On the other hand there are specific-purpose telemetering systems, such as some electric flow meters, with measuring and transmitting elements assembled into one meter body; but even here one finds the primary measurement to be independent of the transmission of the result thereof. This *separateness of measuring and transmitting elements* in the transmitting section characterizes all telemetering systems, and should be borne in mind in studying any system.

Since in the telemetering of non-electrical magnitudes it is first of all necessary to convert them into electrical variables, the problem of "indirect measurement" enters into the science, as do also the related problems entailed by differences of scale laws.

Examples: (1) The usual industrial method of measuring gas flow is to install in the pipe line an orifice, a nozzle, a Venturi or a Pitot tube and to connect this primary device to a manometer: but the differential varies directly with the absolute pressure of the gas, inversely with its absolute temperature and directly with the square of the

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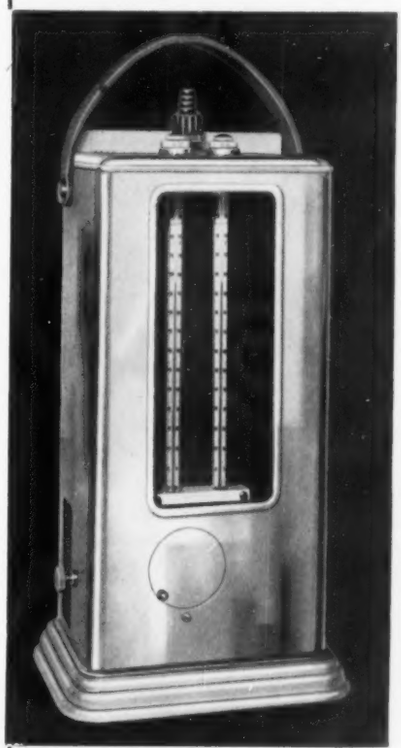

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flow rate, so that telemetering the readings of an ordinary manometer would serve no useful purpose. Not only must the manometer be specially compensated, but the law relating the transmitted electrical variable to the corrected quantity-rate of flow must be such that a number of transmitters, each associated with a manometer, can be joined into a totalization system. (2) Whereas the scale of an individual receiving indicator may be specially calibrated, a receiving *recorder* uses standard printed charts and the entire system must be so designed that the scale law of its final element agrees with that of the chart scale.

4. Possible Classifications.

(a) By Primary Measurements in General.

Theoretically, it seems as futile to classify telemetering systems by their primary measuring elements as it would be to classify telegraphers by the purport of their messages. And yet, in practice, a competent sports telegrapher possesses a set of aptitudes which differs from that of a competent financial telegrapher; so *in practice* one discovers that almost every telemetering system on the market was originally developed for the transmission of the result of some particular kind of measurement. In some instances the designer probably had no other uses in mind. Nevertheless, the actual situation does not justify devoting space to a detailed classification along this line: no list of really mutually-exclusive categories could be drawn up, because many of the older systems on the market have recently been made more widely applicable, while some of the new designers evidently strove for the goal of a universal system.

(b) By Primary Measurements with Regard to Electricity.

A broad classification (or rough grouping) of telemetering systems on the basis of whether the measured magnitude is electrical or non-electrical is distinctly useful, because experience has shown that systems best suited to purely electrical telemetering do not lend themselves so well as others to the transmission of the results of measurements of non-electrical magnitudes—and *vice versa*. This is traceable to the general fact that electrical magnitudes being likely to vary rapidly, the primary measuring elements involved are of inherently small torque, while with other variables encountered in industrial practice the exact reverse is often true. This classification is not used in the treatment which follows, because many systems belong somewhere between the two extremes; but the relative suitability of particular systems for the two classes of variables will often appear.

(c) By Electrical Principle.

A logical classification of telemetering systems is based upon the nature of the electrical magnitude or effect whose variations in the transmitting circuit represent those of the measured magnitude. Electrical units are relatively limited in number, and this basis serves to associate the systems somewhat definitely with the characteristics and limitations of interconnecting circuits. Therefore we shall use as far as possible the following classification by telemetering principles, based on that recommended by the A.I.E.E.:

1. Current.....(Section 5)
2. Voltage.....(Section 6)
3. Frequency.....(Section 7)
4. Position.....(Section 8)
5. Impulse.....(Section 9)

The above terms, representing the electric variables employed in the respective classes, are not all self-explanatory, but each of the five principles will be discussed at the beginning of the section devoted to it, and the functioning will be made clear as the different systems are described.

It will be noted that this classification does not establish mutually-exclusive categories, for some systems on the market are "hybrids" and others are "composites."

SELECTED BIBLIOGRAPHY ON ELECTRICAL TELEMETERING

In the following published references more or less complete descriptive classifications of telemetering systems will be found; and to them the authors are indebted for valuable inspiration in preparing the material of these articles:

B. H. Smith & R. T. Pierce. Automatic Transmission of Power Readings. *Transactions A.I.E.E.* Vol. 43, 1924, pages 303-310.

H. Olken. Electrical Telemetering. *Instruments*, Vol. 5, March 1932, pages 66-74.

Report on Telemetering; Prepared by a subcommittee of the Committee on Automatic Stations and on Instruments and Measurements, American Institute of Electrical Engineers, 1932.

W. Stäblein. Die Technik der Fernwirkanlagen. R. Oldenbourg, Munich & Berlin 1934. (Reviewed in *Instruments* June 1935, page 152.)

Linder, Rex, Stewart & Fitzgerald. Telemetering. *Transactions A.I.E.E.* Vol. 48, 1929, pages 766-774.

Other references to specific types of telemetering systems or installations will appear throughout the text.

INSPECTION and TESTING

DETERMINING IMPACT RESISTANCE OF A FINISH COATING

(Courtesy Bell Telephone Laboratories)

A "Universal" Electrical Test Car for Industrial Plants

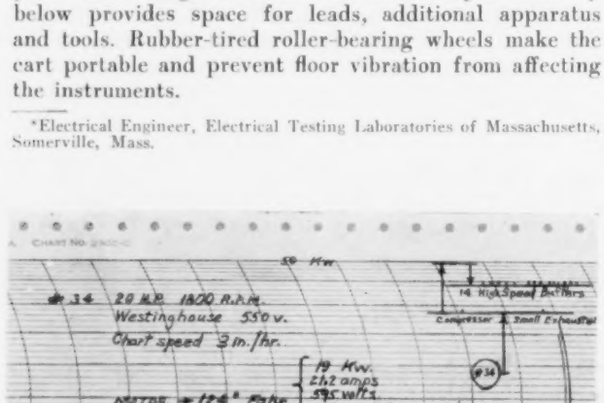
By WILLIAM BARBOUR*

IN striving to continue business with profit during the past four years industrial executives have found it necessary to analyze overhead and production costs more closely than ever before. Information on many cost items is accurately and quickly obtained with electrical instruments. As production is stepped up the value of reliable test data for maintaining good operation efficiency also increases. But without quicker and safer testing methods, tests will naturally be neglected for lack of time and sufficiently skilled personnel. The Universal Analyzer Cart pictured herewith has been developed for testing—

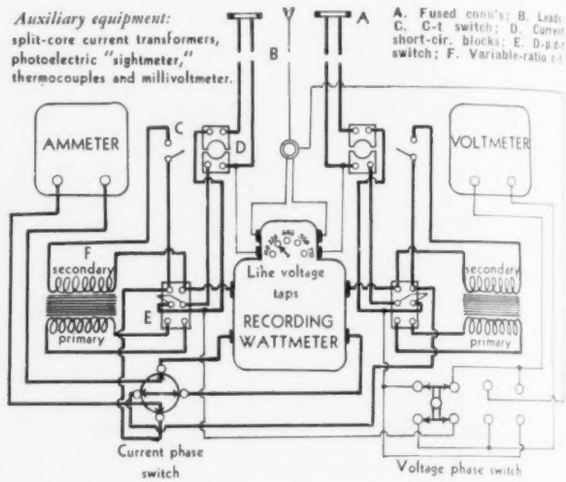
Motors,
Power consumption,
Demands,
Mechanical drives,
Lighting,
Production methods.

It was designed to eliminate a great deal of time and a certain amount of danger in making factory electrical tests. A recording wattmeter introduces the time element necessary on most tests and provides permanent chart records on which conditions, date, time, etc., may be noted. It is an Esterline-Angus Utility Wattmeter with a high chart speed attachment. It operates on d.c. as well as a.c. The Weston indicating voltmeter and ammeter, the variable-ratio current transformers, and the necessary switchgear are also mounted on the top panel. All wiring is concealed beneath this panel. A tray below provides space for leads, additional apparatus and tools. Rubber-tired roller-bearing wheels make the cart portable and prevent floor vibration from affecting the instruments.

*Electrical Engineer, Electrical Testing Laboratories of Massachusetts, Somerville, Mass.



The set is quickly adaptable to 1-, 2-, 3-, or 4-phase systems. Resistors are built in for use on any line voltage from 75 to 800 without necessitating potential transformers. Current transformers provide good scale readings for currents of 1 to 1000 amps. To test loads under 100 amps. it is simply necessary to attach the proper size of dummy fuse cartridges to the flexible leads and insert in place of the actual fuses on the line to be tested. Current transformers may then be set for near



full-scale readings on the wattmeter and ammeter. For heavier loads the split core current transformers are used.

Within a few minutes the following information is made available on a drive or a piece of equipment:

1. Recording of power (chart speeds from 12"/min. to 1½"/hr.)
2. Readings of line voltages across each phase
3. Readings of currents in each line
4. Indication of power factor of load (voltmeter-ammeter method or two-wattmeter method)
5. Test of motor operating temperature
6. Illumination intensity at machines

In analyzing industrial plants with this apparatus the entire plant electrical load is recorded for several days or a week. Then the various departments and individual pieces of equipment are tested. These tests may last only five or ten minutes each, or several hours to a day may be advisable. Floor plans are drawn up and motors, shafts, drives and mechanical equipment are sketched in as the survey progresses. Original test charts and data, mechanical drive diagrams, and plant lay-out plans are then in a form to place on the general manager's desk to be analyzed in relation to power bills, fuel bills, payroll, maintenance expenses, and material costs. The flexibility and simplicity of operation of this test cart make a *perpetual plant analysis* a comparatively easy matter. Accident hazard and time are reduced to a minimum so that an electrician or mechanic can conduct tests on a regular schedule without interfering with his regular duties.

Electrostatic Deflection Methods for Cathode-ray Tubes*

By RALPH R. BATCHER†

ELECTROSTATIC DEFLECTION SENSITIVITY

Electronic emission from heated cathodes is the basic principle of a large variety of electron tubes. The one principle that distinguishes cathode ray tubes from the others is the utilization of the deflection feature. The most common method for applying deflection fields is by means of internal condensers setting up electrostatic fields which vary according to the phenomena under investigation.

The deflection is approximately proportional to the voltage applied to the deflection plates, for a given design of tube and set of operating conditions. This proportionality factor is known as the electrostatic deflection sensitivity. It is conveniently stated as the percentage of the anode voltage required per inch (or centimeter) deflection. In some tubes this rating is given for the stated working conditions of one kilovolt on the anode, and is then expressed in volts per inch deflection.[1,2,3,4,5]

CALIBRATION

The various factors that affect the sensitivity of a cathode ray tube have been mentioned in the preceding article. The calibration constant, however, is ordinarily obtained by measurement at several values of exciting potentials, and a curve is made for future reference. A theoretical analysis of the problem shows that there are four factors that affect the electrostatic sensitivity (neglecting the effect of any focusing arrangement on the velocity of the rays).

(1) The charge and mass of each electron. The actual effect is proportional to the ratio of these quantities, *i.e.*, $\frac{\text{charge}}{\text{mass}}$ or $\frac{e}{m}$

(2) The field due to the deflection plates, which depends upon the applied potential difference and to their separation (directly proportional to the first and inversely as the second).

(3) The length of time that an electron is affected by this field; which is proportional to the effective length of the plates in the direction of travel of the rays, and inversely as the speed of the rays. This is evident since the higher the speed the less time they are under the influence of the field. The effective length of the deflecting plates is somewhat larger than actual measurements would indicate, since there is some edge effect.

(4) The magnifying action of the tube. The ray is deflected a small amount while between the deflecting plates. After leaving this space it continues in the new direction until it strikes the screen. Thus, the greater the distance between the plates and the screen, the greater the deflection.

Combining these four effects in the order named:

$$h = \frac{1}{2}\left[\frac{e}{m}\right]\left[\frac{E'}{d}\right]\left[\frac{l}{V}\right]^2\left[\frac{L}{l/2}\right] \qquad (1)$$

where the symbols are given significance in the diagram, Fig. 1. The velocity of the rays V is in centimeters per

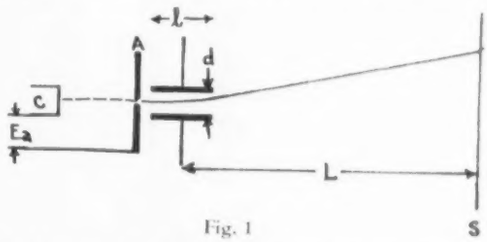


Fig. 1

second. Substituting numerical values for the quantities, and converting to practical units gives:

$$h = \frac{E\,l\,L}{2\,E_a\,d} \qquad (2)$$

or the volts required per centimeter deflection are:

$$\frac{E}{h} = \frac{2\,E_a\,d}{l\,L} \qquad (3)$$

(All linear measurements may be made in either centimeters or inches if the same unit is used throughout.) This determination should be made separately for both sets of deflection plates.

In making the above conversion the following factors were used: $\frac{e}{m} = 1.772 \times 10^7$ electromagnetic units, or $1.772 \times 10^7 \times 300 \times 10^8 = 5.316 \times 10^{17}$ electrostatic units.

$$E = \frac{E'}{300} \text{ and } E_a = \frac{E'}{300} \text{ volts}$$

$$v^2 = 2E_a\,\frac{e}{m} \qquad (4)$$

(except at high anode potentials)

The above formula (2) is the classical form and has been published repeatedly.

The value of the ratio of e/m is of considerable importance in physical investigations. It is considered here as a constant.

Equation (2) has been converted to a nomographic chart, Fig. 2. A straight line intersecting the L and l/d scales at points corresponding to those physical measurements respectively, will intersect the central axis at some point. Another line intersecting this point and the point on the E/a scale, if extended to the h/E scale, will directly indicate on the latter the deflection in centimeters per volt.

VELOCITY OF CATHODE RAYS[6,7]

According to the Theory of Relativity an electron, as its velocity approaches the speed of light, gains in mass by an appreciable amount representing the transforma-

*Second chapter of "The Cathode-ray Oscillograph and Its Applications" being published serially in *Instruments*. This series began in the July 1935 issue.

†Radio engineer; cathode-ray and electronic application specialist, Hollis, L. I., N. Y.

[1]MacGregor-Morris & Mines. Measurements with the Cathode-ray Oscillograph. *Journal Institute of Electrical Engineers*, Vol. 63, 1925, pages 1056-1096.

[2]Mines. The Jet as a Measuring Device. *Journal Institute of Electrical Engineers*, Vol. 63, 1925, pages 1096-1107.

[3]MacGregor-Morris & Wright. Accuracy of Measurements with Gas-filled Cathode-ray Tubes. *Journal Institute of Electrical Engineers*, Vol. 71, 1932, pages 57-82.

[4]Simon and Reich. Ueber ein Universalstativ für Versuche mit der Braunschen Rohren. *Physikalische Zeitschrift*, Vol. 2, 1900, pages 284-291.

[5]Johnson. A Low-voltage Cathode-ray Tube. *Bell System Technical Journal*, Vol. 1, 1922, pages 142-151.

[6]Ackerman. Cathode-ray Oscillograph with Norinder Relay. *Journal American Institute of Electrical Engineers*, Vol. 49, 1930, pages 285-289.

[7]Batcher. Applications of the Cathode-ray Oscillograph. *Proceedings Institute of Radio Engineers*, Vol. 20, 1932, pages 1878-1891.

tion of its kinetic energy into mass. From equation (4) it would appear that at anode potentials of 250 kilovolts and over the electrons are moving faster than the speed of light, which is an impossibility. At high anode potentials (greater than about 50 kilovolts) the equation is in error. In an analysis of this problem, a more accurate equation for the actual velocity is (utilizing symbols heretofore described)

$$\frac{v}{c} = \sqrt{1 - \frac{1}{(1+X)^2}} \quad \text{where } X = \frac{E_a e}{c^2 m}$$

Substituting practical units as,

$$E_a = E'_a \div (299.86 \times 0.99958)$$
$$c = 2.9986 \times 10^{10}$$
$$e/m = 5.305 \times 10^{17}$$

gives the following:

$$X = 0.001968\, E_a$$

$$\text{and } \frac{v}{c} = \sqrt{1 - \frac{1}{(1 + 0.00197\, E_a)^2}}$$

This equation has been plotted in Fig. 3.

Several other factors affect the velocity of the electrons among which are: magnetic focusing fields, molecular density of the gas, the negative space charge due to the electrons returning after striking the screen.[3] These effects are mainly important in the case of low velocity rays.

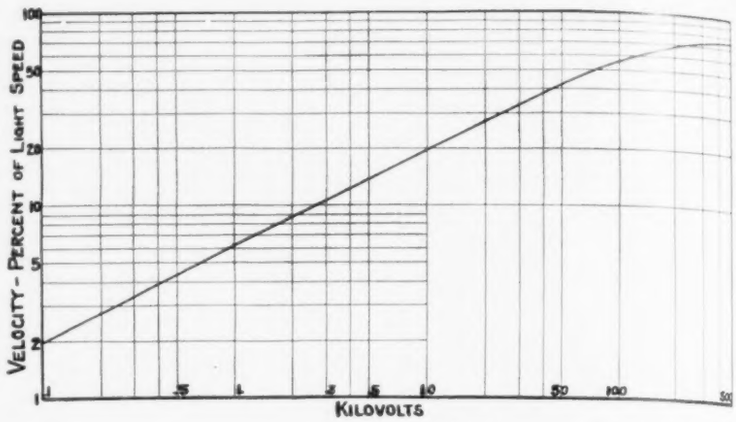


Fig. 3

THE DEFLECTION PLATES

Usual practice has been to place the deflection plates inside the tube, where they remain in one definite position and parallel at all times. This permits the making of a calibration curve so that the potential required for a given deflection can be predetermined.

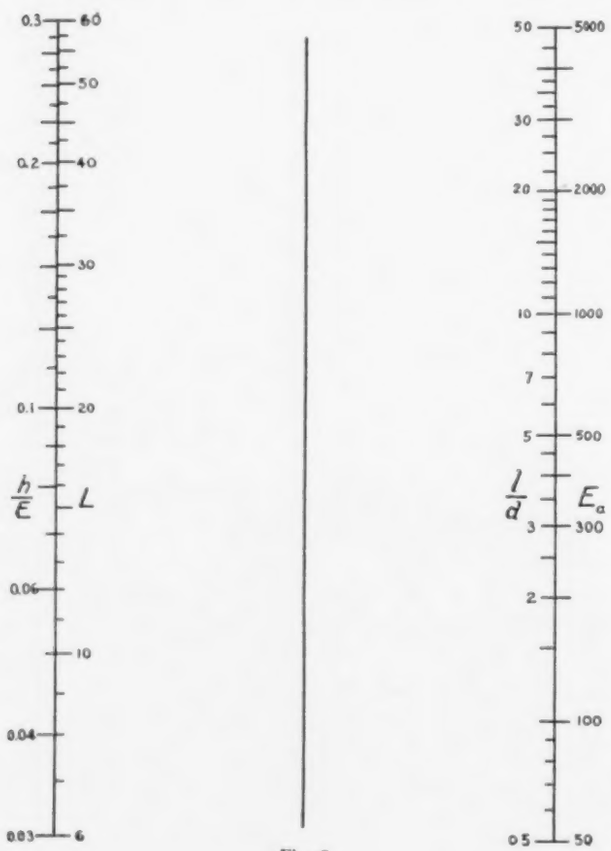


Fig. 2

The sensitivity is also increased since much closer spacing is permitted. When two or more pairs of plates are supplied, they obviously cannot be placed at the same point, so they must be placed in tandem. This makes one pair somewhat more sensitive than the other, if the separation is the same on both pairs (the pair that is the closer to the screen is the less sensitive). In commercial designs a separate terminal may have been provided for each plate, or two of the plates (one of each pair) may have been connected to the anode terminal. As an example, in the RCA Type 906 tube, Fig. 4, this triple connection is made inside the tube and brought out to the anode terminal (which usually is maintained at ground potential). Otherwise, it is desirable that each pair of plates be maintained at a definite potential with respect to the anode. It is necessary that a definite conductive circuit be provided between them, even if the resistance of this path be as high as several megohms. All unused deflection plates should be connected to the anode to prevent a charge from accumulating on them, which would cause the axes to shift. This charge is mainly due to the electrons wandering back through the tube after striking the screen.

With tubes having separate leads brought out from each of the deflection plates, the shunting resistance across each pair should be center-tapped to the ground (or to the anode). This compensates for a type of distortion produced wherein the deflection potential affects the axial velocity of the ray, thereby in turn affecting the sensitivity. When one of the deflection plates is directly connected to the anode, the deflection depends upon the factor $\left(1 \pm \frac{hd}{lL}\right)$ since the plate that has a positive deflection potential at any moment theoretically increases the axial velocity by the reciprocal of the above factor.

Several investigators have described tubes wherein the final axial velocity of the ray (the factor that determines the brilliance of the spot) is increased immediately before the ray strikes the screen. A tube of this type developed at the Bureau of Standards will be described in a subsequent article.

SHAPE OF DEFLECTION PLATES

It is not necessary that both pairs of plates have equal areas. In an experimental tube built by the author, the second pair of plates flared out and furnished the support for a small coated mica screen about 1½″ square. This additional area provided high deflection sensitivity although the path of the beam was unusually short. The magnifying action usually produced by the longer path

Fig. 4

between the deflection plates and the screen was obtained in this instance with an optical lens suitably selected and arranged.

Fig. 5

In a *general-purpose* tube it is essential that the plates of each pair lie in parallel planes and that the planes of one pair be at right angles to those of the other.

In some special purpose tubes there are three deflection plates with axes at 120° to one another (Fig. 5), for studying three-phase circuits and apparatus.

In the design of any general purpose tube it usually is the practice to make the tube as sensitive to electrostatic deflection potentials as possible. There is not much leeway in the design and arrangement of the deflecting plates when this requirement is rigidly adhered to, since the greatest sensitivity is obtained when the ratio $\left(\frac{\text{length of the deflection plates}}{\text{spacing between the plates}}\right)$ is equal to $\left(\frac{\text{distance from center of plates to the screen}}{\text{radius of the screen.}}\right)$ This relationship is based on the assumption that there is no need of a deflection greater than the radius of the screen, and upon plane parallel plates. Examination of a number of commercial tubes shows that they are rarely as sensitive as the above relationship would permit.

Additional sensitivity (with a possibility of being more than doubled) can be obtained with plates in diverging planes (see Fig. 4) the edges nearest the anode having the least spacing. It also has been suggested that the plates have a parabolic curve but the gain over plane diverging plates is small.

In the case of plane diverging plates with closest spacing d_1, and widest spacing d_2, the deflection (measured at the point where the ray leaves the field) is increased to very nearly $\sqrt{d_2/d_1}$ times that which would be found with parallel plates with a separation of d_2. However, the curvature of the path between the plates is no longer parabolic, so that a different magnification factor, due to the length of the tube, must be applied.

External deflection plates are rarely effective—especially in soft or gaseous tubes—as the sensitivity is not constant unless special precautions are taken to prevent electrostatic charges from accumulating on the inside surface of the glass. Such charges usually exert enough shielding to neutralize entirely the effect of external plates.[8]

The width of the plates need only be enough to cover the lateral movement of the rays. When relatively narrow plates are used, however, the supporting and connection wires to the plates have a greater influence, and may distort the field between the plates, making the oscillograms difficult to analyze.

In some cases where the actual deflection does not need to have a linear relation with the applied potentials, other shapes for deflection plates have been used, as for example curved segments cemented to the inner wall of the glass, as in a tube used for frequency comparisons by the Bureau of Standards.[9] In another tube films of magnesium deposited on the inner walls served as deflection plates.[10]

As stated above, the deflection is dependent upon the length of time that an electron is affected by the electrostatic field. If the ray is deflected from the axial direction by the effect of the first deflection plates, its *axial* velocity is unchanged although its speed is greater. The path being at an angle, the length of the ray path between the second plates is consequently greater. These two effects cancel each other so that the actual deflection produced by the second deflection plates does not depend on whether the ray has been previously deflected by the first plates. The second pair of plates should therefore be rectangular, and any attempt to introduce specially shaped plates (as for instance annular sectors, etc.), will cause non-linearity.

DEFLECTION ACCURACY

An analysis of the accuracy and dependability of the deflection system must consider several factors: linearity (proportionality of the deflection amplitude with the applied potentials); constancy* (or freedom from variations due to external conditions); and errors due to effects that the application of the deflection system has on the circuit under test.

In any two-pair tube it is essential that the pairs of plates be mounted at right angles to each other (as mentioned above) and also that the leads and support wires do not influence the deflection system. The deflection plates and support wires must not be magnetized. Inaccuracies in the physical lineup of the elements will always cause trouble and the user of the tube is usually unable to correct the results.

It is impossible to keep all applied voltages constant over long periods so as to permit a calibration curve to be etched on the glass, but by keeping the anode and grid bias voltage constant the calibration "constants" will be fairly constant.

NORMALITY

This term will be used in discussing the deviation of the axes from the perpendicular. It often is assumed that the cause of this discrepancy is solely the variation in the alignment of the plates. Another cause of such distortion is the effect of the deflection voltage upon the axial velocity of the ray. When large deflection voltages are applied, the velocity of the ray increases or decreases as the plates become positive or negative.

In some tubes, such as the recent designs by Cossor and Co., where the anode surrounds and shields the deflection plates, and tubes where the anode takes the form of a conductive coating on the inner surface of the glass, this variation is eliminated. If the effect is large, a field shaped like a kite or trapezium replaces the usual rectangular field occupied by the oscillogram, somewhat as illustrated in Fig. 6. The distortion is reduced, but not

[8]Jones & Cravath. Neutralization of the Deflection Field with External Electrodes. *Physical Review*, Series II, Vol. 29, 1927, pages 871-879.

*Inasmuch as the theoretical deflections, such as might be obtained from the nomographic chart, Fig. 2, are approximate (because of the difficulty of exactly determining the dimensions of the field, which are larger by the edge effect than the dimensions of the plates) variations from those theoretical values are not considered errors except when due to factors that affect the calibration constants. Tubes are usually more sensitive than theory indicates, due to the lowering of the velocity of the electrons caused by gas ionization[11] and to an increase in the effective area of the plates due to the fringing effect. As an example, the reduction of the velocity due to ionization in the Western Electric Co.'s No. 224 tube is reported by Johnson as equivalent to a reduction in the anode voltage by 50 volts.

[9]Nicholas & Malmberg. Registration of Cathode Rays. *Bureau of Standards Journal of Research*, Vol. 8, 1932, pages 61-65.

[10]Selenyi. Ueber die weitere Entwicklung der neuen, mittels electrostatischer Ladungen, Schreibenden Kathodenoszillograph Röhren. *Zeitschrift für Technische Physik*, Vol. 10, 1929, pages 486-489.

[11]MacGregor-Morris & Henley. Sensitivities of Gas-focused Cathode-ray Tubes. *Journal Institute of Electrical Engineers*, Vol. 75, 1934, pages 487-496.

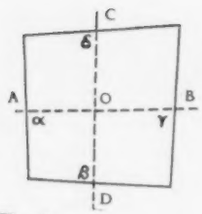


Fig. 6

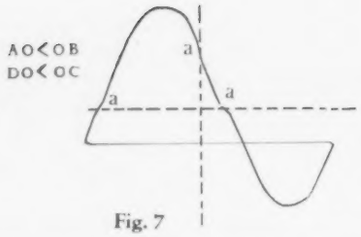


Fig. 7

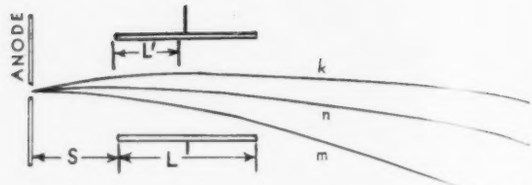
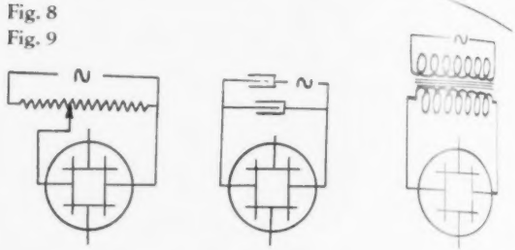


Fig. 8

Fig. 9



necessarily eliminated, if separate leads are provided for each plate, not internally connected to the anode circuit, so that a center tapped leak resistance can be connected across each pair of plates. The tap of these two resistances can then be connected directly to the anode or else kept at a definite potential with regard to the anode potential.

It is believed that trepezoidal diagrams attributed to the above cause are often due to magnetized electrodes, and to the field from the leads supporting the deflection plates, from the various support wires extending beyond the anode and from the effect of non-parallel deflection plates.

Since linearity is an essential factor in measurement work, it may be desirable to compare the accuracy of different tubes. A suggested numeric for the normality factor is the mean value of the four angles (acute or 90° but not the obtuse angles) which the edges of the figure, representing the actual field, make with the horizontal axis and with a line drawn perpendicular to this axis. (The figure should have a diagonal length equal to the nominal diameter of the screen). Thus in the hypothetical figure (Fig. 6) if the measured angles α, β, γ and δ are 88°, 87°, 85°, and 88° respectively, the average value for this factor is 87°.

THRESHOLD EFFECT

The most important calibration discrepancy is due to the threshold effect.[8,12,13] The deflection plates are prone to collect stray free electrons (those returning to the normal circuit after striking the screen and others due to impact ionization) and so become negatively charged. If a leakage path is not provided (as by a high resistance connected across the plates) this charge will quickly cause the spot to wander off the screen. Even when such a leak is provided, a space charge exists between the deflection plates so that the sensitivity is reduced when the applied voltage on the plates is small (below five or ten volts). The effect is the same as if a small variable bias voltage were connected so as to oppose the deflection voltage.

While this error is small, this contraction of the figure caused by the spot slowing down as it crosses an axis as at the points "a" in Fig. 7, is usually objectionable, and a number of methods have been proposed for its elimination.

Partial compensation for this error can be made by measuring all deflections to the outer edge of the trace instead of to the estimated center of the spot in each position. This increases the apparent deflection by an amount equal to half the diameter of the spot. The threshold effect in the usual low-voltage gas focused tube may cause a discrepancy of about 0.040 inch, on either side of zero. It is not present with magnetic deflections.

It has been shown that this effect is reduced (possibly eliminated) if a biasing potential is connected permanently in series with the leak resistance. Unfortunately this deflects the spot to the edge, or else off the screen, so that it must be restored to a useful location by the application of magnetic fields, by the physical location of the electron gun to aim at the opposite edge of the screen, or by utilizing a warped tube envelope so designed that the center of the screen coincides with the new location of the spot. It is the author's opinion that many of the proposed cures introduce more errors than the original effect for the following reasons: If the field between the anode and the outer end of the deflection plates is greatly disturbed the deflection may be altered, somewhat as illustrated in Fig. 8. In other cases the magnetic field is not constant over the whole travel of the ray, a condition especially true if this magnetic field is applied to the path beyond the deflection plates.

In the case where the electron gun is aimed at the edge of the screen there is a substantial difference in the length of the path as the spot moves around, causing a difference in the deflection sensitivity. Moreover, the spot strikes the screen at an angle and will not focus as sharply.

In some cases (where the deflection plates have separate leads not tied in with the anode) some improvement results if the leakage resistor across each pair of plates has a center tap which is connected to the anode through a battery of about 100 volts so that the anode has a higher positive potential than the mean potential on the plates.

Another method of keeping the threshold effect low in gas focused tubes is to use as low a filament current as possible consistent with sharp focusing.

With high vacuum tubes (which do not use the gas ionization principle for focusing) the threshold effect is minimal and except in rare instances can be ignored.

DEFLECTION AMPLITUDE ADJUSTMENT[14,15,16]

Whenever the applied potentials produce excessively large deflections, it becomes necessary to reduce them in some definite manner, or to control the sensitivity of the tube. When the required reduction is not large the first method is usually the easiest since increasing the anode voltage will also produce greater brilliance.

In many cases, increasing anode voltage is inconvenient. The procedure necessary then depends entirely upon the gas content of the tube. In the case of highly exhausted tubes where there is very little ionization no precautions are necessary and the voltage can be cut down by any method consistent with the frequency, such as slide wire resistors or voltage dividers using two condensers or resistors in series, as shown in Fig. 9. In

Continued on page 225

[12]Ekersley. Design of Broadcasting Stations—Modulation Studies. *Journal Institute of Electrical Engineers*, Vol. 66, 1928, pages 501-520.

[13]Bedell & Kuhn. Linear Correction for the Cathode-ray Oscillograph. *Physical Review*, Series II, Vol. 36, 1930, pages 993-996.

[14]Rogowski, Fleger & Klemperer. Die Spannungsteilung beim Kathodenoszillograph. *Archiv für Elektrotechnik*, Vol. 23, 1930, pages 579-588.

[15]Austin. Canal Rays. Scientific Paper No. S23 of the Bureau of Standards, 1905.

[16]Burch. Potential Dividers for Cathode-ray Deflection Control. *Philosophical Magazine*, Series VII, Vol. 13, 1932, pages 760-774.

NEW INSTRUMENTS

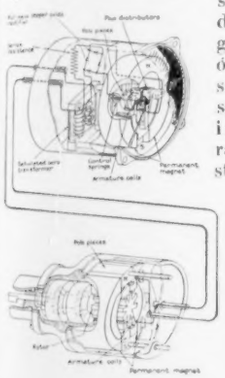
In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions.

When writing to manufacturers directly, please mention this department as your source of information.

Or write to Information Section, Instruments Publishing Company.

Electric Tachometer

Developed for aircraft but suitable for various industrial plant applications, a new speed-measuring system announced by the General Electric Co. comprises a small, light, inductor-type generating unit of relatively slow rotor speed, and an indicator arranged for A-N standard mounting, connected by two leads. *Principle:* The frequency output of the generator (proportional to engine r.p.m. by reason of positive drive) is conducted to the primary of a small transformer at the rear of the indicator case. The transformer core saturates at a voltage output given by the generator at less than 100 r.p.m. After the transformer core is saturated, the voltage in the secondary coil is directly dependent on the frequency of the primary coil. This a-c. voltage is then rectified to d-c. through a small copper-oxide rectifier, which also is in the instrument case. The measuring element is a d-c. millivoltmeter. *Features.* The generator can be driven in either direction; no polarity need be observed in connecting the two leads. Utilization of this type of circuit minimizes moving parts (see diagram). There is no step-up gearing in the generating unit; nor are there brushes, slip rings, or other forms of sliding contacts. The indicator movement has high torque which, combined with aperiodic damping, results in steady readings under extreme vibration. The instrument has a 270° scale and a 2¾" dial. The standard tachometer can be supplied for scale readings of 0-2500, 0-3000, 0-3500 r.p.m., with generator speeds of one-half the indicated r.p.m. Special tachometers can be supplied for a wide variety of applications. The indicator can be supplied with any desired scale marking.



Machine Temperature Indicator

The Ideal Commutator Dresser Co. has developed a convenient "spot" device called the "Ideal Tel-Temp" for quick determination of temperature in motors, bearings, compressors, pumps, grinders, etc. It is a small dial thermometer, attached easily to the machines, and reads from 0° to 100° C. The base has a threaded stud that screws into the case, and is attached to the machine frame with escutcheon pins. The case has a flexible rubber ring that fits tightly against the machine, keeping ambient temperature fluctuations from affecting the readings. Thus it can be installed on machines permanently or used as a portable tester. By having the required number of bases, one Tel-Temp case can be used as a semi-permanent installation on several machines. For installation on open motors, a special plastic-ring jacket is supplied to shield the Tel-Temp from the effects of cross currents of air.

Self-checking, Multi-range Laboratory Instrument

Combining self-checking features with 29 ranges for both a.c. and d.c., the "Little Laboratory," a new all-purpose, portable laboratory instrument announced by the Rinfield Electrical Instrument Corp., contains a built-in standard cell that allows the user to check

the instrument at any time. The lowest range of either a.c. or d.c. can be checked directly and corrected if necessary by a magnetic shunt accessible from the outside. Thus the unit can be checked against its standard cell, and adjusted for any temperature. This is said to hold true even for the 2-millivolt range (ordinarily seriously affected by temperature changes). D.c. ranges include full-scale capacities from 200 microamps. to 10 amps. in 6 steps, and from 2 millivolts to 1000 volts in 8 steps. A.c. ranges are from 10 milliamps. to 10 amps. and from 0.3 to 1000 volts, with 29 ranges in all. Galvanometer included has two windings (low-resistance sensitive to low potentials, and high-resistance for small currents) both of which are accessible for external use. Instrument scale, 5.5" long, hand drawn on white enamel, is calibrated at 20 points. Guaranteed accuracy in terms of full-scale is 0.25% for d.c. and 0.50% for a.c. ranges ⁄ 4,000 cycles. Case is 17½" long, 8½" deep and 6½" high including cover.

New Possibilities for

REMOTE FLOW CONTROL

for steam, water, brine, oil, gas or chemicals.

Wilbin has developed a system of remote electric valve control in positive, but infinitely variable steps which presents new flow control opportunities.

A valve of any size, for any pressure, can be held at any desired position between open and closed, in accordance with an electric impulse from any desired distance.

From 6 to 13 separate steps can be provided, so spaced as to vary the rate of flow by definite increments, every few seconds, either by a hand switch or automatically.

APPLICATIONS

Temperature Control: A complete line of thermostats is available for every service in industry or for heating or air conditioning.

Liquid Levels: Where levels are maintained by pumping, the valve will either throttle the flow or control steam to the pump or turbine. The impulses can be given by an altitude switch or a float mechanism. Distance is no object.

Time Cycles: In combination with a suitable time switch, any desired cycle of graduated flow can be provided.

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MOTOR VALVES

have these advantages:

Absolutely silent in operation. Quick opening and closing without shock.

Return automatically to the closed position when current fails. Can never remain partly open.

Powerful thrust action.

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Current consumption 25 Watts.

Wilbin Instrument Corp.
183 MADISON AVENUE
NEW YORK, N. Y.

Stop Worrying!

It is possible that your company's competitors may, at any time, place on the market a product cheaper and better than your own. The worst part of it for you is that the new product will accomplish the same purpose as yours and yet be based on entirely different physical principles with no infringements of your patents.

There are about forty different thread-locking devices on the market. Edison once proposed forty-eight different ways of performing a certain ore-milling operation. There are at least three fundamentally different types of photocells on the market. And so on. . . .

But you may not know that although an invention type problem has many solutions, their number is not infinite and can be reasonably estimated. Moreover, all the solutions of one problem *are logically interconnected*. This means that if you happen to think of one solution you may, if you know how, trace many other solutions, thereby protecting yourself from unpleasant surprises years later.

In our home study course on the Theory and Technique of Inventive Practice we teach, among other important (to you) and original subjects, how to trace the remaining solutions in case you happened to think of any one.*

The course consists of twelve lessons. It requires one evening per week to go through one lesson per month. You will enjoy the reading and will be surprised to learn how many things you never thought of before, although you perhaps should have. For executives, we have a special Discussion Method which does not require the filling in of examination papers and grading. These particular students just have a good time arguing. It requires NO special technical education to study this course—any one from a mechanic to a president can and should take it.

The tuition fee is very reasonable—$65.00 on terms and $60.00 if paid within thirty days after enrollment. To readers of *Instruments* we offer special terms: $5.00 down and twelve monthly payments of $5.00 each.

Take this course and stop worrying. Fill in the coupon and mail it to us with your down payment. By return mail you will receive the first four lessons of the course (bound in one volume) and will be on your way toward a highly valuable, pleasant and unusual experience.

*Some engineers do not like the word "inventing." We are sorry, but can use no other word, because any new idea in engineering is a product of the inventive imagination.

Trofimov School of Inventive Practice, Inc.
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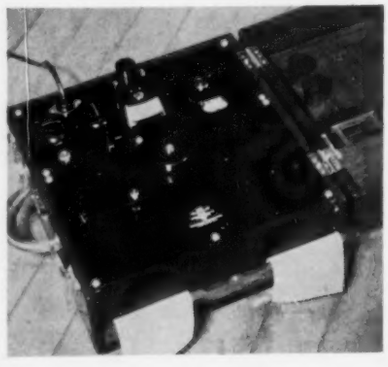
Photoelectric Colorimeter

Designed for chemists in all fields, who have to do colorimetric analysis, the American Instrument Co.'s new Yoe Photoelectric Colorimeter not only relieves eyestrain and increases the ease of making comparisons, but is

capable of giving quantitative results more accurately than is possible with any method of visual comparison. Developed by Dr. John H. Yoe, of the University of Virginia, it has had several years of use in his laboratory before being released for general use. The instrument uses samples of either 5 ml. or 100 ml., in special plane-bottom glass tubes, and gives directly quantitative readings, referred either to a standard solution, or to a Corning filter as reference standard. The photocell is a Weston Photronic of suitable characteristics. The parallel beam from the light source strikes this cell after passing up through the tubes. Suitable diaphragms reduce the beam diameter to avoid meniscus distortion and tube-wall reflections.

Photoelectric Color Comparator

The "Telecolor" announced by the Hays Laboratories is designed for evaluating numerically the color differences between two specimens. The differences, it is said, can be measured both spectrally and from their reflection values. A side door in the 20-lb. handled case exposes, when open, two apertures before which the test samples are placed. The galvanometer pointer deflects toward the lighter sample. At the upper right hand corner of the panel is a graduated dial which, when turned to restore the pointer to mid-scale indicates the value of the difference. In order to determine the spectral difference between two specimens, six color filters ("representing the six points of the spectrum") are inserted in the instrument in proper sequence and the values with each filter are jotted down. The light source can be plugged into any electrical outlet, and permits tests to be made day or night. The life of the Hays Telecolor is said to be "practically indefinite." The instrument is said to require no servicing or attention, except replacing the light source, should it burn out. It is simple to operate.



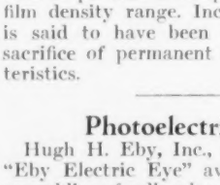
Photoelectric Exposure Meter

Tripled sensitivity, to provide camera settings at low levels of brightness, characterizes the Weston Electrical Instrument Corp.'s new photoelectric exposure meter. As in previous models, light reflected from the scene to be photographed is transformed into electric energy by a Photronic cell and deflects a microammeter calibrated in brightness units, but the microammeter has been redesigned to provide increased deflection at the lower end of the scale. The result is a range of brightness values corresponding to ¼ to 1000 candles per sq. ft. A "multiple-lens" glass window, placed over the photocell to restrict the

light reaching it to that within the usual camera angle, replaces baffles previously used which caused a loss of more than one-half of the light reflected from the scene. The upper dial, on which the photographer co-ordinates his choice of film speed, filter factor, aperture and shutter speed on the basis of a definite light value, has also been re-designed for more convenient and rapid use; it now is said to provide a complete indication of film density range. Increased sensitivity is said to have been obtained without sacrifice of permanent electrical characteristics.

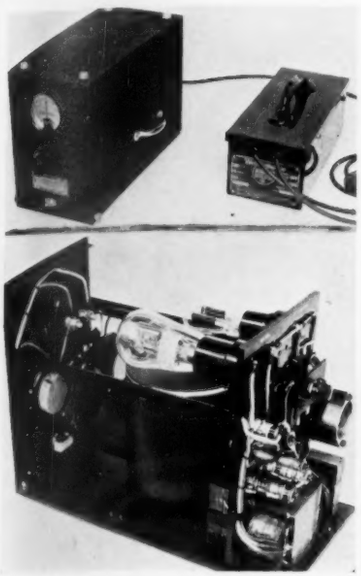
Photoelectric Cell

Hugh H. Eby, Inc., announces a new "Eby Electric Eye" available singly; in assemblies of cell, relay, tube, resistances, socket, etc.; or in kits for home or laboratory experiments. Said to have "the advantage of being sensitive in both the generative and emissive classes, it consists essentially of two metal electrodes hermetically sealed in Bakelite between which a light-sensitive material is exposed to incident light rays behind a special glass or quartz window. It reacts to both the intensity and wave-length of the incident light rays. Unaffected by continuous exposure to light and entirely electronic in action, its operation depends upon the light-sensitive surface emitting electrons which are proportional in number to the incident light flux. It can be used as a primary element for measurements, as a component part in suitable circuits to operate relays or (when connected to the input of a vacuum-tube amplifier) to perform operations which are to be completed in 0.0001 second.



Photoelectric Color Matcher

The human eye having a logarithmic response to illumination (constant percentage sensitivity to differences), the indicating instrument on a color matcher should respond to changes in light intensity with a scale deflection proportional to the ratio of the difference to the total amount. Another consideration is that objects are truly matched in color if they look alike to the eye when viewed in the light from *any* source, so that the problem requires matching at several points along the visible spectrum. These results are achieved in the Westinghouse



Elec. & Mfg. Co.'s new color matcher. Moreover, in order to match colored surfaces without regard to gloss, it is essential to "see" only the "hue" or diffused color. (Glossy materials reflect light of all colors from the surface independently of the true color of the material.) The optical system of the new instrument transmits diffused color to the phototube, but the gloss-reflected light is returned toward the lamp. The new color matcher also incorporates a bridge arrangement to balance out the plate current, thus increasing the useful sensitivity. The phototube has a linear response to light, resulting in linear changes in grid bias, and the indicating instrument (microammeter) has a deflection of a definite current per division. The necessary logarithmic response is obtained by an amplifier tube circuit so designed as to have a curved grid-plate characteristic. Taking 4 volts as a typical point, a change of 0.8 volt or 20% produces a change of ½ milliamp., or full-scale deflection on the scale which has 20 arbitrary (equal) units, 40 divisions, each scale unit thus representing about 1%, which is the average eye sensitivity. The range of intensities covered by the amplifier, with equal percentage sensitivity, is about 5.5 to 1, thus giving a range of 30 to 1 in light intensity over which sensitivity is above 60% of the maximum. The light intensity used is sufficient to give the maximum usable grid bias on the lower resistor, with a maximum sensitivity phototube when a white surface is being measured, and the range down to 5% reflectivity is covered without loss of sensitivity. Below this the sensitivity decreases, but "colors" in this range are "black," and even dull black surfaces reflect 2% or more of the incident light. Fluctuations in line voltage are compensated largely by the novel circuit, and moreover a static saturated core type of regulator is used. A double knob controls the selection of the light filter and the setting of the potentiometer to balance out the plate current. Four rubber feet on the top permit the instrument to be inverted for testing small samples. The instrument is compensated also for self-heating effects by making one of the bridge resistors partly of copper wire, which increases in resistance when heated, balancing out the effect of heat on the regulation of the transformer supplying the lamp.

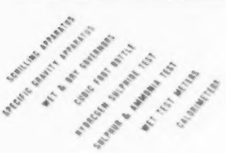
Photoelectric Control of Paper-roll Register

In paper-bag machinery and printing presses it is essential to have the edge of the paper closely controlled as to position. Rolls which have become dished on the ends by reason of rough handling give trouble unless the side register is thus kept correct. The Smith & Winchester Mfg. Co., in conjunction with engineers of a large electrical company, has developed a rapid mechanical controller for guiding the edge of a web even at speeds as high as 600 ft./min. The photoelectric primary element of this controller is located so as to view the edge as it travels past it, and through rapid relays commands a mechanism powerful enough to shift the heavy roll axially in order that variations will not exceed ± 1/16". The complete control unit takes the place of the regular paper roll stand from which the tuber or other machine is fed.

Multi-circuit Pyrometer

The "Almor" Horizontal Edgewise Pyrometer announced by Illinois Testing Labs., Inc., comprises a ruggedly constructed, high-resistance, aperiodically-damped vertical-shaft millivoltmeter, combined with a selector switch (for 8, 17, 18 or 25 circuits) into a water- and fume-proof and dust-tight unit. Scale is 6" long. Cold-junction adjusting screw is

provided. Dimensions are 7¼" wide × 10¼" high × 7" deep. Net weight is 13 lbs. A wide variety of thermocouples and connecting leads is available, as well as automatic cold-junction compensation, and also a special double-switch arrangement for up to 48 circuits.



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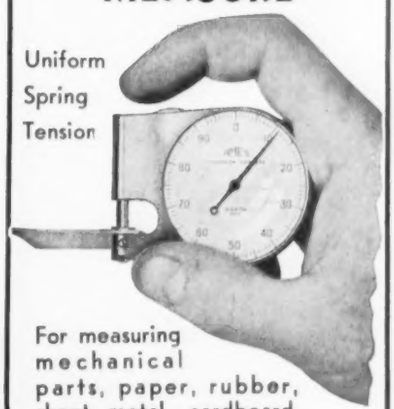
AMES THICKNESS MEASURE



For measuring mechanical parts, paper, rubber, sheet metal, cardboard, veneer, glass, leather, wire, etc. Made of rustless metal. Fully guaranteed.

A speedy, accurate, durable gauge, reading in thousandths of the inch with a capacity of 5/16".

Other sizes and styles for all measuring purposes. Send for catalog.

Price $9.50 fully guaranteed

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PYRO THE SIMPLIFIED OPTICAL PYROMETER

SELF-CONTAINED, DIRECT READING RUGGED— FOOL-PROOF

Unique construction enables operator to rapidly determine temperature even on minute spots, fast moving objects, or smallest streams; no correction charts, no accessories.

New concentrated test mark and ease of operation permit unusually close and rapid temperature determinations.

Stock Ranges 1400° to 5500° F.

PYRO RADIATION PYROMETER

The ideal instrument for Furnace or Kiln use. Gives actual heat of material aside from furnace or kiln temperature. Does not require a skilled operator,—strictly automatic. Eliminates personal errors. Always ready to tell within three seconds any shortcomings in your equipment. Stock Ranges 1000° to 3600° F.

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RAWSON Multimeters

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13 RANGES
From 1 Microamp to 1 Amp and 20 Microvolts to 1000 Volts

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THERMAL
13 RANGES
From 2 Milliamp to 1 Amp and 60 Millivolts to 1000 Volts

Types 501A, B & C. Also Type 502 Thermal.

Dynamometer wattmeters, milliammeters and voltmeters. Also ultra-sensitive meters both for A.C. and D.C., fluxmeters, electrostatic voltmeters from full scale 120 volts to over 20,000 volts, thermocouples, earth current meters, cable testers, fluxmeters, etc.

Special Apparatus Built to Order.

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Air-operated Controllers

The Consolidated Ashcroft-Hancock Co. announces a new line of "Controlographs" for temperature or pressure, in square-case recording models and round-case non-recording models. The principle and the main features of the Controlograph were described in *Instruments*, June 1933, page 128; the new models differ therefrom chiefly in design of cases and in mechanical refinements.

24-hour Program Controller

The Tork Clock Company, Inc., announces "Tymit," a new portable plug-in type time switch. Finished in Bakelite and chromium, it is 5" high x 4" wide x 2¼" thick. Weight 1½ pounds. Black or Walnut finish. With standard 24-hour dial and adjustable operating arms, it has been designed for the control of radios, refrigerators, protective lighting, fans, window signs, etc., but appears to be suitable also for industrial applications, being available in a wall-mounting model (capacity 1500 watts) for permanent control of oil burners, etc The portable Tymit (illustrated) has a capacity of 660 watts.

Temperature Controller

In the new "Type 34T" self-contained automatic temperature controller brought out by the Foster Engineering Co. the energy required for operating the diaphragm-motor valve is obtained from the controlled medium itself: the pressure in the space below the diaphragm is that ahead of the valve, while the pressure in the space above the diaphragm is the reduced downstream pressure further reduced by a pilot valve. This pilot valve is actuated by the bellows of a thermal system which is set by means of a graduated scale. An "overtravel device" protects the bellows from the effects of excess temperature in the event of a by-pass being opened too much or of a valve leaking. The only work required of the thermal system at any time being to actuate the pilot valve, there is thus made possible a combination of close control and wide adjustment range unobtainable in conventional self-operating controllers. It is claimed that there is no wire-drawing of valve or seat such as is caused by double-seated valves. Construction is of all-bronze, semi-steel and bronze or special metal alloy internal parts. Standard ranges 0-100°F., 90-200°F., 190-300°F. Sizes ½" to 3". Working pressures 10 to 200 lbs. in.². Special units and bulbs for higher temperature and special services.

Electro-hydraulic Controller for Machine Tools, etc.

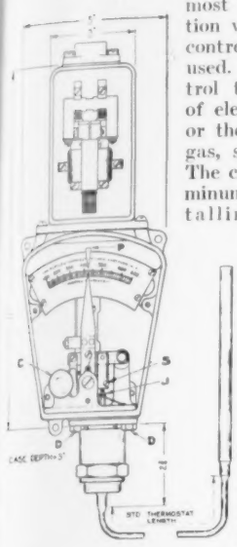
Many combinations of automatic feeds and rapid traverses are provided by means of this new unit brought out by Vickers, Inc. Starting, reversing and stopping are controlled electrically by push buttons or limit switches, relays and solenoids built into the control panel. A synchronous time relay (varied by turning a dial in panel) provides delayed reverse. The different feed rates and rapid traverses are controlled hydraulically, being increased or decreased by stops (on work table) that depress one or the other of the two center plungers. Length of any working stroke or rapid traverse is varied at any time by simply changing position of stops. Lever provides manual control for set up purposes. Changes in work resistance or operating pressure of hydraulic system do not affect feed rates and it is said that tool jumping and overfeeding are thereby prevented. Panel provides complete hydraulic circuit except pump and cylinder; it is flush mounted with gasket and requires no pipe connections. It is available in several types and sizes.

Temperature Control for Internal Combustion Engines

An electric contact temperature control for use on water-cooled internal combustion engines is announced by Edison Electrical Controls Division of Thomas A. Edison, Inc. Its nucleus being sealed in a glass tube filled with an inert gas, the contact points cannot oxidize or become pitted by repeated operation; and loss of calibration due to continuous operation or tampering is prevented. This sealed contactor is mounted in a metal tube provided with a standard pipe thread and a suitable junction box for electrical connections. The combination, designated "M6-DS Control," may be mounted in the cooling water of a Diesel engine (1) to signal an attendant when a predetermined temperature is reached; (2) to stop the engine when the temperature approaches a dangerous degree; or (3) to hold the temperature of the water constant by varying the flow. In gas engines it may regulate the flow of water or it may cut off the ignition by opening the primary of the ignition coil or by grounding out the magneto. It is also used on supervised gas engines to sound an alarm.

Temperature Controller with Built-in Relay

The Partlow Corp. has announced "Model MRR," a mercurial type remote-bulb form self-contained temperature controller with built-in relay, which can be adapted to almost any application where electric control is to be used. It will control the operation of electric heaters, or the flow of air, gas, steam, or oil. The case is of aluminum, black crystalline finish. A nickeled knob on the front of the cover is for changing the controlled temperature. As it is turned a red indicator hand moves over a temperature scale, and a black pointer indicates the actual temperature on the same scale. This instrument may be furnished for almost any desired temperature range up to 1000°F., standard ranges being 50° to 350°F., 100° to 650° F., and 100° to 1000°F. A Burgess "Micro-Switch" embodied in the mechanism gives positive current interruptions with relatively small temperature differentials, and the mercury-in-steel thermal system assures sensitiveness. The relay is of the solenoid pusher type and has a capacity of 15 amps. a.c. This instrument may also be furnished without the relay for use with currents up to 5 amps. a.c.



Gas-air Ratio Control

The P.D.M. Proportional Mixer, developed by The Philadelphia Drying Machinery Co., consists of a diaphragm-actuated control valve, known as a Zero Governor, which feeds gas at atmospheric pressure to an inspirator into

which the gas is drawn and mixed with air. Equality of pressures assures constancy of the ratio set by means of a valve controlling gas flow to the inspirator. Suspension, of the control diaphragm from an extra-long coil spring, and the use of a disk type valve, are said to assure sensitive, friction-free operation in immediate response to the slightest pressure change.

Processing Controllers

Self-operating pressure and temperature controllers designed especially for regulating processes in the food industries are announced by the Consolidated Ashcroft Hancock Co. The illustration shows "Type 2260 D Retort Controller" for the regulation of *pressures* within the usual retort range of 3 to 18 lbs./in.² with setting point at 10 lbs./in.² It is said that high sensitivity is assured by an extra-large diaphragm top, and that the pressure can be raised "more quickly than with ordinary controls since the valve does not begin to close until the pressure has been raised close to the final holding point." Available sizes are ¾", 1" and 1¼". The self-operating *temperature* controllers have a seamless two-ply bellows and another feature is the anchoring of the capillary tube's braided armor in such manner that no strain is imposed on the bellows when the tubing is moved. One model of the self-operating temperature controllers (made in sizes from ⅜" to 1½") is a *combined controller and indicator*, there being a 3½" dial thermometer mounted on top of the bellows housing.

Paper Folding Tester

The cohesive properties of paper, irrespective of tensile, bursting strength, etc., are determined by a new motor-driven, steel cabinet housed, Folding Endurance Tester manufactured by the Amthor Testing Instrument Co. *Operation:* The specimen is held under standard tension by two jaws of the floating type which are "kept in perfect horizontal alignment by frictionless supports." A reciprocating blade double-folds the paper until it breaks. The number of folds is registered on a 4-digit counter, which is instantly disengaged when the specimen breaks, the motor also being stopped at that moment.

Surface Temperatures

Flat Stationary or Moving Curved Surfaces

The "Alnor" Combination Pyrocon

Ideal for rolls, molds, plates, platens and plastic material temperatures.

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Employing the highest grade non-reactive wire-wound resistor units and the most modern methods of insulation.

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Send for Bulletin 900-H describing these instruments.

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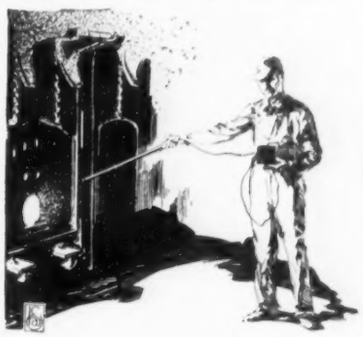
THWING

Radiation Pyrometers



The Thwing Portable Radiation Pyrometer is a handy pyrometer to have in any plant or laboratory.

It is easy to use and gives accurate readings directly in degrees temperature. Simply point the radiation tube at the hot object and a temperature reading is secured in 15 seconds.

No calculations, no matching of colors, no batteries.

Illustration shows temperature reading being taken of steel in open hearth furnace.

414

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METERS—PYROMETERS

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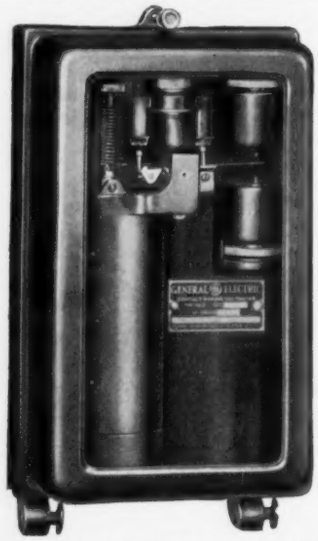
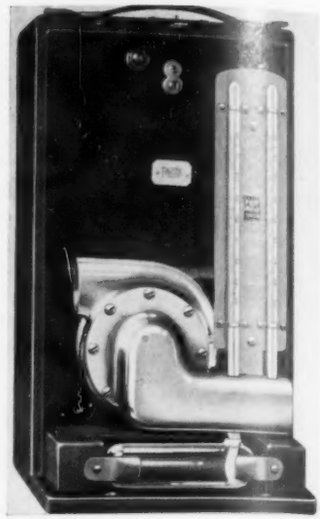
Contact-making Voltmeter

A new contact-making device for feeder voltage regulators, "Type TSB-20," announced by The General Electric Co., is said to eliminate needless operations, consequently increasing the life of both itself and the regulator and minimizing maintenance. The iron core of a solenoid is suspended from a compensating spring and is flexibly spring-coupled to one end of a contact beam. The beam is pivoted at the center, and with a given voltage applied to the solenoid winding, the system is held in mechanical equilibrium. The beam is fitted with two contacts, one of which on changing voltage closes a circuit to the regulator relay switch magnet and causes the regulator motor to operate. At the instant the contacts close, holding coils are energized, providing additional holding pressure. Micrometer adjustments are provided to hold a mean



voltage level and regulate the width of the voltage band. Where the regulator motor is supplied from a separate source of power, when the feeder becomes de-energized the solenoid core drops and operates a cutout, automatically running the regulator to the full-lower position so that when feeder voltage is restored there will be no possibility of the regulator impressing higher than normal voltage on the feeder. Assembly of the compensating spring directly above the solenoid core permits the use of an unusually lightweight contact beam pivoted in spring-mounted sapphire cups. A spring coupling between the contact beam and the solenoid core stem absorbs frequency vibrations which would otherwise interfere with accurate control of voltage band width. When contact is made and the holding coil is energized, the stationary contact is lifted from its stop and both contacts then float together. Chattering is thus prevented, arcing minimized, and calibration maintained.

So that advantage can be taken of full sensitivity, the instrument is equipped with a damping-vane assembly on the lower solenoid core stem. This prevents overshooting but in no way interferes with normal operation. There are said to be approximately 90 fewer parts than other instruments of like nature. Temperature changes of the component parts neutralize one another.

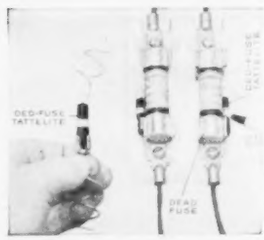


Aspiration Psychrometer

The new portable aspiration psychrometer announced by The Palmer Co. has been developed especially for the air-conditioning industry, its feature being that the fan motor is operated by two small dry cells in the case, thus permitting tests in the parts of a plant where electric outlets are not handy or in unwired storage buildings, etc. In other respects it is of conventional design and construction, except that its case permits handling less delicately than laboratory psychrometers. A humidity chart is furnished with the outfit.

"Tattelites"

Two models of tiny neon lamps and casings have been brought out by Littelfuse Labs.: The "Ded-Fuse Tattelites" (illustrated) connect directly in parallel with the fuse and draw no current until the fuse has blown. They are adapted for use on any size cartridge or plug fuses, since they measure only 1¾" long overall ×5/16" max. diam. and have 6" connecting leads. They are designed for circuits of 100 to 550 volts a.c. or d.c. and light on only 0.0005 amp. A protective resistance is built in. Other uses are indicating open circuits, switches, relays, etc.



"Indicator Tattelites" are a line of tiny neon pilot lights which tell when a motor, heater, electric clock, etc., is operating either directly or in remote control circuits. Conversely they can be made to indicate open circuits or switches, blown fuses, etc. They operate on 90 to 250 volts a.c. or d.c., consuming about 1/1000 amp. ("a cent-a-month"). Not affected by vibration. Life is 3,000 hours. The neon bulb used in this lamp is said to be the smallest commercially used in the world (1" long × ¼" diam.). Octagon shaped bases are similar to those used on switchboard lamps. Dead front panel type mountings with clear phenolic resin caps are available.

Thermionic Tube Tester

Representing a departure from former types in electrical and mechanical design, as well as in appearance, the Weston Electrical Instrument Corp.'s new tube tester has socket mountings covering all pin combinations for present glass and metal tubes, with provision for combinations which may be introduced in the future. Three separate loads (for general-purpose tubes, for battery types and for diodes) are available, permitting total-emission tests for each type on a specific load basis, without possibility of damage to the tube structure. Seven individual electrode switches provide a highly flexible means of setting up the various electrode combinations for any type of tube. Individual portions of all tubes may be checked without removing tube from socket. A complete inter-element neon short test may be made while the tube is hot in the socket used for emission readings. The dust-proof cast aluminum case is divided in the center by an engraved Bakelite panel section carrying the indicating instrument and all controls. Fuses within the Bakelite plug on the line cord make it unnecessary to open the instrument for fuse replacement. Overall dimensions are 12" × 9¼" × 6". A carrying case is available.

Vacuum Power Switch

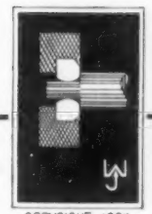
The Continental Electric Co. announces "Types VPS-1 and VPS-2" of a new vacuum power switch wherein a solenoid controls the position of the contacting mechanism, sealed in a high vacuum chamber, which itself is hermetically sealed in a metal container preventing oxidization or difficulties with particles of inflammable material cast off during processing, so that the switch can be used in corrosive or inflammable atmospheres. It can be used also for remote and automatic control and high-voltage installations, as its construction is said to eliminate pitting or burning of contacts. Service life under normal operating conditions is said to be practically unlimited. The VPS-1 and VPS-2 are single-pole, single-contact switches, normally open and normally closed, respectively. The switch is cylindrical, 5½" overall, 1½" diameter. Maximum continuous load ratings on a.c. are 20 amps. at 110 volts or 10 amps. at 220 volts; on d.c. 20 amps. at 110 volts, 10 amps. at 220 volts.

Differential Pressure Recorder

An 11" (chart diameter) recorder announced by Morey & Jones, Ltd., was developed for fluid metering, liquid level recording and other differential-pressure applications. Employing a flexible metallic bellows instead of the conventional mercury U-gage, it may be transported and used in any position and may be calibrated for any differential from 20" water full-scale to 10 lbs./in.² full-scale. Working pressure limit is 500 lbs./in.² for standard construction (higher limits special). *Features*: By unscrewing the plug on top of the bellows housing at the rear of the round case, the calibrated spring may be removed without affecting any other part of the instrument, and a spring of different capacity readily substituted. The zero adjustment is "outside" (protected by a cap). Limit stops prevent injury in the event of greater differential than the one for which the particular spring in use was calibrated. Friction is said to be negligible at the bellows-motion transmitting shaft bearing, the stainless-steel rod being lapped in and provided with an instrument-life-time supply of grease. *Integrator*, supplied for fluid metering applications is electrically operated, direct-reading and independent of friction or clamping devices (see *Instruments*, April 1934, page 80). *Other Options*: Static pressure pen; alarm contacts; indicator scale read from pointer at end of pen-arm.

Wheatstone Bridge

Designed and constructed especially with a view to being ordered in quantities for students and service men and for factory production uses, a box type Wheatstone bridge announced by The Muter Co. is for measurement of resistance from 0.01 ohm to 11 megohms. The rheostat has three decades with a total range of 11,100 ohms adjustable in steps of 10 ohms. The ratio arms are controlled by a single switch providing seven decimal multipliers. A "C" battery is built into the bridge, as is a galvanometer. However, extra binding posts are provided for external battery and external galvanometer. The galvanometer resistance is 115 ohms, and the sensitivity 7 microamps. per division. *Accuracy*: The ratio arm resistors are adjusted to ¼% and the resistors in the rheostat to ½%. This provides an accuracy of approx. 1% for the intermediate steps of the multiplier, decreasing to perhaps 5% at the extremes. Heavily silver plated wiping contact snap switches minimize contact resistance losses. *Dimensions*: 9¾"x8⅜"x 5½". *Net Weight*: 6 lbs. *Internal Construction* is said to "set a new standard for mechanical design."



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MANUFACTURERS' NEW LITERATURE

In this department we list each month the printed matter issued by manufacturers. Unless otherwise noted, any of the items listed may be secured free upon application to the issuing firm. Manufacturers who have not yet sent in their printed matter are invited to do so.

C173 **Driftmeter Junior.** Folder describes a direct reading, mechanical instrument for surveying the drift in oil wells. Folder also includes its operation and maintenance. Driftmeter, Inc., National Bank of Tulsa Bldg., Tulsa, Okla.

C174 **Constant Temperature Water Bath.** 6-page folder gives details on a water bath, claimed accuracy 0.01°C. E. H. Sargent & Co., 155 E. Superior St., Chicago, Ill.

C175 **Potentiometers.** Bulletin 270 gives data and prices on several potentiometers: Type B High Precision; Portable Precision; Brooks Deflection; Precision Laboratory; Simplified Laboratory; and Portable Slide Wire. Rubicon Co., 29 North 6th St., Philadelphia, Pa.

C176 **Pressure Blocks.** Bulletin No. 98 describes the application of pressure blocks to steel rolling mills. Advantages of the use of blocks in mills are given. Baldwin-Southwark Corp., Philadelphia, Pa.

C177 **Profile Gages.** 8-page attractively printed catalogue illustrates a number of profile gage types and their applications. Stockton Profile Gauge Corp., 165 Jackson St., Lowell, Mass.

C178 **Visual Gage.** 4-page bulletin illustrates various gage types. Sheffield Gage Corp., Dayton, Ohio.

C179 **Automatic Reset Timers.** 2-page bulletin lists several types, also contains information on magnetic switches. Zenith Electric Co., Inc., 607 S. Dearborn St., Chicago, Ill.

C180 **Testing Machines.** Catalogue No. 2338 is made of illustrations which show the very extensive line of testing machines manufactured by Losenhausen. Captions of illustrations are given in German, French, English and Italian. Alfred Suter, 500 Fifth Ave., New York, N. Y.

C181 **Pressure Gage Stabilizer and Protector.** Leaflet illustrates device for protecting boiler pressure gages by preventing live steam from coming in contact with the gage springs. Boiler Equipment Supply Co., Inc., 210½ West Commerce, Oklahoma City, Okla.

C182 **Snap Gages.** Catalog No. 4 describes an adjustable snap gage, ranges and prices are given. Meldrum-Gabrielson Corp., Syracuse, N. Y.

C183 **Scientific Instruments.** General catalogue, 100 pages, contains information on the instruments manufacturered by P. J. Kipp & Zonen, Delft, Holland.

C184 **Vacuum Instrument Pump.** 4-page folder describes a device which was developed to operate the air driven types of aircraft navigating instruments. Eclipse Aviation Corp., East Orange, N. J.

C185 **Direct Reading Flowmeters** developed to measure the instantaneous rate of flow of liquids in gallons or pounds per hour, are particularly adaptable to internal combustion engine testing. 4-page folder. Eclipse Aviation Corp., East Orange, N. J.

C186 **High Vacuum Pump.** Catalogue sheet describes a pump with a guaranteed vacuum of .001 mm. National Scientific Corp., 814 N. Franklin St., Chicago, Ill.

C187 **Boiler Water Level Control.** 24-page bulletin discusses the importance of boiler water level control, then the manufacture and construction of the control are covered. Installation and wiring diagrams are included. McDonnell & Miller, Wrigley Bldg., Chicago, Ill.

C188 **Thermometers.** Catalog No. 135 is a loose-leaf, 32-page catalog. It covers: industrial thermometers, various types; long extension type thermometers; special industrial thermometers and general use thermometers. Scientific Instrument Co., 531 W. Larned St., Detroit, Mich.

C189 **Resistance Thermometers.** Bulletin 4001. This 24-page booklet tells the owner, the architect, the engineer and the contractor what each needs to know about electrical thermometers. It may be had by asking Leeds & Northrup Company, 4901 Stenton Ave., Philadelphia, Pa.

C190 **Orifice Flow Provers.** Bulletin E-8 discusses the Pierce Critical Flow Orifice Provers for testing positive displacement meters. Various factors for substitution in the formula are given in tabular form. American Meter Co., 60 E. 42nd St., New York, N. Y.

C191 **Non-Inductive Resistors.** The April issue of the Ohmite News describes the new non-inductive resistor. Ohmite Mfg. Co., 636 N. Albany Ave., Chicago, Ill.

C192 **Some Causes of High Costs.** Bulletin No. 335 gives a number of case histories showing how the graphic instrument reduces costs, improves products and processes and eliminates waste of power and labor. Esterline-Angus Co., Indianapolis, Ind.

C193 **Temperature Control.** Leaflet briefly covers a thermostat control for a temperature of 1600°-1800°. Burling Instrument Co., 185 Market St., Newark, N. J.

C194 **Gas Stethoscope.** 4-page bulletin describes the application and use of the Gilmore gas stethoscope for the determination of leaks in gas mains. E. R. Gilmore, 214 E. 1st St., Topeka, Kan.

C195 **Marine Service Rotameter.** Leaflet describes a Rotameter equipped with a center-pole for use where operating conditions are such that a standard free floating rotor may be caused to strike against the tube. Schutte & Koerting, 12th and Thompson Sts., Philadelphia, Pa.

C196 **Hydrogen Ion Meter.** Supplement to List 108 describes the electrometer valve pattern meter. The Morton glass electrode system is also described. Cambridge Instrument Co., Inc., Grand Central Terminal, New York, N. Y.

C197 **Precision Measuring Tools.** Catalog 34, 20 pages, lists light wave equipment, reference gage blocks, taper insert plug gages, thread measuring wires, sine bars, light wave flatness tester, light wave micrometer, light wave deflection bar, and special gages. Van Keuren Co., 12 Copeland St., Watertown, Boston, Mass.

C198 **Static Pressure Controls** for accurate control of low pressures, are described in a 4-page folder. Installation, wiring, pressure connections and adjustment are also covered. Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

C199 **Time and Sequence Controls** for industrial processes and general applications are covered in a 4-page bulletin of the Leland Electric Co., Dayton, Ohio.

C200 **Mercury Switch.** Form F74 gives a brief description of the design and operating characteristics of the switch produced by the Leland Electric Co., Dayton, Ohio.

C201 **Smoke & Combustion Indicator.** 2-page bulletin description. T. W. McNeill Engineering Equipment Co., 4057 Van Buren St., Chicago, Ill.

C202 **Precision Instruments & Gaging Devices.** Description Publication No. 3, 12 pages describes the Comtor system of gaging and illustrates a number of applications to particular types of gages. Comtor Co., Waltham, Mass.

C203 **Humidistats & Thermostats.** Bulletin K, 4 pages, is a complete catalog of Friez humidistats. Bulletin T/X, 2 pages, illustrates the insertion humidistats and thermostats for insertion into air conditioning cabinets, into ducts, incubators, etc. Julien P. Friez & Sons, Inc., Baltimore, Md.

C204 **Industrial Indicating Thermometers.** Bulletin 600, 4 pages, gives illustrations and data on vapor pressure thermometers.H-B Instrument Co., Inc., 2518 N. Broad St., Philadelphia, Pa.

C205 **Cycle Regulator.** Bulletin No. 80B, 8 pages, illustrates a cycle controller which eliminates separate panel mounting and many control pipe connections. Installation diagrams are given. Fisher Governor Co., Marshalltown, Iowa.

C206 **Sensitive Draft & Pressure Recorders.** Bulletin 2017 illustrates a new line of recorders. Bulletin gives ranges and applications. Hays Corp., Michigan City, Ind.

C207 **Valve Position Indicator.** Illustrates several models of valve position indicators, with specifications and prices. Tefft-Jackson, Inc., 830 Hospital Trust Bldg., Providence, R. I.

C208 **Vehicle Operation Recorder.** Form A-296 illustrates the Ohmer Kienzle Vibracorder used for checking vehicle and machine operation. Ohmer Fare Register Co., Dayton, Ohio.

C209 **Mercury Switches.** Catalog Sec. 12, 8 pages, gives data and section diagrams showing operation of Con-Tac-Tor mercury switches. Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

C210 **Attachable Colorimeter Lamp.** Leaflet D-28A describes this lamp for use with colorimeters, in place of random illumination. Bausch & Lomb Optical Co., Rochester, N. Y.

C211 **Two-Position Controller.** Catalog Sec. NC24A, 4 pages, gives a description and specifications of a 2-position micromax controller. Prices are also included. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

C212 **Waco Service.** A house organ put out by Wilkens-Anderson Co., 111 N. Canal St., Chicago, Ill., describes a Bakelite press for mounting specimens for metallographic work.

C213 **Electrical Insulation Manual.** This new Manual is devoted to the subject of electrical insulation as it concerns those who are responsible for the installation, care and maintenance of practically all types of electrical apparatus; and is intended to be up-to-date and comprehensive so far as the testing of insulation resistance is concerned. While this new Manual does not render obsolete the previous editions bearing a similar title (dating back as far as 1923), it is intended to amplify the subject of insulation testing in a manner that should be appreciated by those having to do with that very fundamental factor in electrical equipment. Price 25 cents. Copies of this book will be sent without charge to those having reason to be interested. James G. Biddle Co., 1211 Arch St., Philadelphia, Pa.

C214 **Insulation Testing.** Bulletin No. 400, describes the complete group of Standco insulation testing sets. This bulletin replaces older bulletins and also includes an announcement of the new Dwarf Megohmer. It also contains an advance announcement of the Junior Paragon constant pressure Megohmer. Herman H. Sticht & Co., 27 Park Place, New York, N. Y.

C215 **Timer.** Leaflet illustrates and describes an automatic timer which has been equipped with a magnetic coil and special brake finger to control the timer escapement. Walser Automatic Timer Co., Graybar Bldg., New York.

C216 **Resistors.** Ohio Carbon Co., 12508 Berea Road, Lakewood, Ohio, has just issued a folder describing their new low resistance LV "Ohiohm" carbon resistors used for increasing the sensitivity range of certain types of industrial electronic control apparatus and radio hook-ups. Several graphs, compiled from the results of thousands of tests, illustrate the useful properties of these resistors, as regards their life and overload qualities, their constancy of value under extreme humidity conditions, and their load and voltage characteristics.

C217 **Resistance Wire.** Wilbur B. Driver Co. (formerly Gilby Wire Co.) has just published a new 60 page resistance handbook. This manual contains a great many tables and charts pertaining to the design and construction of electrical heating units, and will be of keen interest to the engineering profession. Copies may be had by simply writing to the main office and works located at Riverside Avenue, Newark, N. J.

C218 **Humidistats.** Bulletin A illustrates and describes in detail the new range of Friez wall mounting and insertion type humidistats. Julien P. Friez & Sons, Inc., Baltimore, Md.

C219 **Indirect Microscope Illumination.** Bulletin 17 describes the personal experiences and applications to which the Ultrapak has been placed by scientific workers. There are a number of photomicrographs and testimonials indicating the advantages through the use of this equipment in bacteriology, pathology, medicine, biology, chemistry and other fields. Bulletin 18 describes the complete equipment. E. Leitz, Inc., 60 E. 10th St., New York, N. Y.

C220 **Relays.** Bulletin AT/R illustrates and describes Friez relays and control assemblies for use in conjunction with Friez humidistats and thermostats. Julien P. Friez & Sons, Inc., Baltimore, Md.

C221 **Control.** Engineers confronted with the exacting problem of maintaining precision control of temperature, pressure, rate of flow or liquid level on continuous processes which involve time lags and load changes, should write to the Taylor Instrument Companies, Rochester, N. Y., for a copy of their new Bulletin 37R.

C222 **Temperature Control.** Hart Mfg. Co., Hartford, Conn., announce a new Bulletin No. 13-A in which is illustrated their newest temperature control equipment. Dimensional and wiring diagrams of direct break indicating and non-indicating thermostats for electric ranges and water heaters. Also thermostats with remote control for the same purposes.

C223 **Pressure Regulators.** McAlear Mfg. Co., 1901 South Western Avenue, Chicago, recently published a 96-page bulletin describing all types of regulators for reducing and controlling steam, water, air, gas and oil pressures. Engineering data and charts form an important part of this new book.

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ELECTROSTATIC DEFLECTION METHODS for Cathode-Ray Tubes—*Continued from page 216*

such tubes with low ionization, high leak resistors (5 to 10 megohms) can be used across the plates and their effect disregarded. When ionization occurs in the tube due to the presence of gas molecules, several precautions must be observed. The conductive path between the deflecting plates increases the load upon the circuit under investigation. When the power output in the circuit under test is low it is possible that a simple series resistance will prove satisfactory if a high resistance shunt is used across the plates. The exact value depends upon the conductive path, so that a calibration is necessary in order to determine the voltage equivalent of any deflection.

In case more power is available to operate the deflection plates without abnormal loading of the test circuit, a high-resistance voltage divider will give better results. If the total resistance of this "potentiometer" is less than about 0.1 megohm the voltage applied to the plates can be determined from the position of the movable arm, since the resistance shunt due to the deflecting plate path is usually much greater than this value.

When it is not possible to connect a resistance load across the test circuit without upsetting the circuit conditions, a condenser-resistance combination may be used, or a vacuum tube buffer stage. The capacity reactance of the condenser is of small importance if correctly selected but its leakage resistance must be of a high order.

Usually, however, it is not difficult to compute the total voltage if the total circuit impedance is known. In the case of hard tubes where the internal losses due to gas ionization are not important, a small series condenser will reduce the applied potential if the plates are shunted with a larger one, as in Fig. 9, the reduction being in accordance with the usual rules for series impedances. For very low frequency tests however the condenser's losses become increasingly important, and a step-down transformer may be utilized, as in Fig. 9.

In a subsequent article a piezoelectric "transformer" designed by the author, with characteristics especially adapted for the amplitude control of transients, will be described.

(To be continued)

ORIFICE COEFFICIENTS FOR VISCOUS LIQUIDS — DISCUSSIONS—*Continued from page 205*

dentally this will give some indication of the validity of the area ratio factor in the common formula which has never been adequately proved.

For the liquids used the absolute viscosity should be reported in relation to temperature preferably in c.g.s. absolute units. There is no real advantage in bothering about kinematic viscosity if density is associated with velocity and mass flow made the prime variable in working formulas or in Reynolds numbers, in fact, for some cases there is an advantage where density and absolute viscosity change with temperature at materially different rates.

Reference is made in the article to precautions against air entrainment, but nothing is said about what these were or assurance given that the liquids were really air-free. In this connection it is to be noted that air may be absorbed by the liquids and if the latter are near saturation, a depression of pressure will release air from solution so that it becomes entrained. The air content of liquids subjected to basic tests should be known and proved to be less than will make them saturated at a locally lower pressure point in the system.

In the first paragraph of the section entitled "Calculations and Results" it is stated that there is a difference of opinion as to the validity of the formula, which is true, but the pros and cons should be discussed and not ignored.

Considering the conclusions, it is most remarkable that no instability of the coefficient of discharge has been found over the range of Reynolds numbers reported, when all existing data on flow resistance coefficients point clearly to an unstable zone in this same range of Reynolds numbers. This situation should not be left as it is but should be cleaned up. The first step is that noted previously, the plotting of Stanton curves of flow resistance to see where the unstable zone lies for such resistance as is made by a sharp-edged orifice. Then, if the coefficients of discharge are not unstable in this zone of unstable resistances, some explanation must be found after first verifying the facts.

By EDGAR BUCKINGHAM*

THIS seems to me to be a very interesting and valuable piece of work. It is interesting as a great extension of the older experimental work of Hodgson, Johansen and others on flow through orifices at low Reynolds numbers, where the effects of viscosity become important. This helps toward a better understanding of what really happens in an orifice meter and why it happens; and any such classification of our physical ideas about this complicated phenomenon is most welcome. And the article is practically valuable, because the authors have not limited themselves to describing an admirable experimental research but have put their results into such form as to be immediately available to engineers. I congratulate the authors on a very nice piece of work.

*National Bureau of Standards, Washington, D. C.

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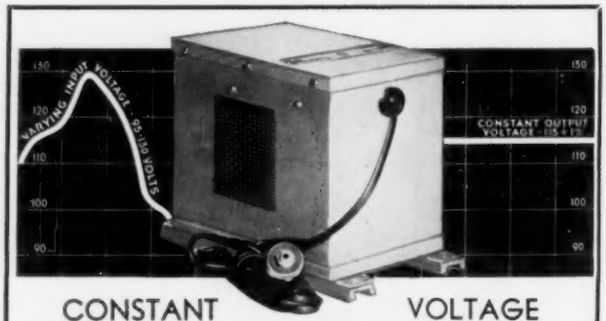

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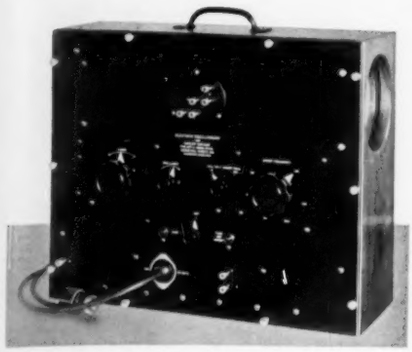

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General Electric Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

PRESSURE RECORDERS
American Meter Co.
Bailey Meter Co.
George Sidney Binckley
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.

PRISMS
Gaertner Scientific Corp.

PROCESS TIMING & SIGNALING INSTRUMENTS
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.

PROVERS
American Meter Co.

PSYCHROMETERS
Recording
Bristol Company
Brown Instrument Co.
Foxboro Co.
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.
Sling
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.

PYROMETERS
Optical
Pyrometer Instrument Co.
Radiation
Indicating
Brown Instrument Co.
Pyrometer Instrument Co.
Taylor Instrument Cos.
Thwing Instrument Co.
Recording
Brown Instrument Co.
Pyrometer Instrument Co.
Taylor Instrument Cos.
Thwing Instrument Co.
Thermo-electric
Immersion
Bristol Company
Brown Instrument Co.
Foxboro Co.
Pyrometer Instrument Co.
Roller-Smith Co.
Taylor Instrument Cos.
Thwing Instrument Co.
Wilbin Instrument Co.
Indicating
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Thwing Instrument Co.
Wilbin Instrument Co.
Recording and Controlling
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Thwing Instrument Co.
Wilbin Instrument Co.
Surface Contact
Bristol Company
Brown Instrument Co.
Pyrometer Instrument Co.
Taylor Instrument Cos.
Thwing Instrument Co.

PYROMETER CALIBRATING SETS
Thwing Instrument Co.

RADIATION TUBES
Pyrometer Instrument Co.

RADIO FREQUENCY OSCILLATORS
General Radio Company

RADIO SET ANALYZERS
Weston Elec. Inst. Corp.

RADIO TEST PANELS
Shallcross Mfg. Co.
Weston Elec. Inst. Corp.

RADIO TUBE CHECKERS
Weston Elec. Inst. Corp.

REGULATORS—See Controls

RELAYS
J. P. Friez & Sons, Inc.
General Electric Co.
Kurman Electric Co.
Roller-Smith Co.
Ward-Leonard Elec. Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.
Light Sensitive
Kurman Electric Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

REMOTE METERING EQUIPMENT
American Meter Co.
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
General Electric Co.
Pioneer Instrument Co.
Westinghouse E. & M. Co.

RESISTORS
General Radio Co.
Roller-Smith Co.
Shallcross Mfg. Co.
Ward Leonard Elec. Co.
Westinghouse E. & M. Co.

RETICLES
Fish-Schurman Corp.

RHEOSTATS
General Radio Company
Ward Leonard Elec. Co.
Westinghouse E. & M. Co.

SACCHARIMETERS
Taylor Instrument Cos.

SCALES
Gaertner Scientific Corp.
Basis Weight
Testing Machines, Inc.
Thwing Instrument Co.
Differential
Thwing Instrument Co.

SHUNT METERS
Bristol Company
Roller-Smith Co.

SCRIBERS
Ford Motor Co.

SHUNTS
General Electric Co.
Rawson Elec. Inst. Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

SIGNALING DEVICES—Automatic
Bristol Co.
Brown Instrument Co.
Foxboro Co.
J. P. Friez & Sons, Inc.
Pioneer Instrument Co.

SINE BARS
Ford Motor Co.

SMOKE ALARMS
Weston Elec. Inst. Corp.

SPECIAL COILS
Ward Leonard Elec. Co.

SPECIAL ELECTRICAL INSTRUMENTS
Bristol Company
Brown Instrument Co.
J. P. Friez & Sons, Inc.
General Electric Co.
General Radio Co.
Kurman Electric Co.
Pioneer Instrument Co.
Rawson Elec. Inst. Co.
Roller-Smith Co.
Shallcross Mfg. Co.
Thwing Instrument Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

SPECIAL INSTRUMENTS
J. P. Friez & Sons, Inc.
Roller-Smith Co.
Thwing Instrument Co.

SPECTROGRAPHS
Bausch & Lomb Opt. Co.
Gaertner Scientific Corp.

SPECTROMETERS
Bausch & Lomb Opt. Co.
Gaertner Scientific Corp.

SPECTROPHOTOMETERS
Bausch & Lomb Opt. Co.
Gaertner Scientific Corp.

SPECTROSCOPES
Bausch & Lomb Opt. Co.
Gaertner Scientific Corp.

SPEED INDICATORS
See Tachometers

SPEED RECORDERS
Bristol Company
Brown Instrument Co.
J. P. Friez & Sons, Inc.
Thwing Instrument Co.

SPEED REGULATORS
Ward Leonard Elec. Co.

STANDARD CELLS
Weston Elec. Inst. Corp.

STRAIGHT EDGES
Ford Motor Co.

STRAIN GAGES
General Electric Co.

STROBOSCOPES
General Radio Co.
Westinghouse E. & M. Co.

SUNSHINE RECORDERS
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.

SURGE INDICATORS & RECORDERS
General Electric Co.
Westinghouse E. & M. Co.

SYNCHRONOSCOPES
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

SYNCHRONIZATION FORKS
Electrical
General Radio Co.

SYNCHRONOUS MOTORS
General Electric Co.
Pioneer Instrument Co.
Westinghouse E. & M. Co.

TACHOMETERS
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
Foxboro Co.
Pioneer Instrument Co.
Roller-Smith Co.
Thwing Instrument Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

TACHOSCOPES
Brown Instrument Co.

TELEMETERS—See Remote Metering

TELESCOPES
Bausch & Lomb Opt. Co.
Gaertner Scientific Corp.

TENSOMETER (Huggenburger)

TESTING MACHINES
Testing Machines, Inc.
Thwing Instrument Co.
Bending
Testing Machines, Inc.
Hardness
Testing Machines, Inc.
Impact
Testing Machines, Inc.
Impact (very light load)
Testing Machines, Inc.
Thwing Instrument Co.
Magnetic
Kurman Electric Co.
Paper
Testing Machines, Inc.
Thwing Instrument Co.
Westinghouse E. & M. Co.
Penetration
Thwing Instrument Co.
Stiffness & Bending
Testing Machines, Inc.
Thwing Instrument Co.
Stretch
Testing Machines, Inc.
Thwing Instrument Co.
Tearing
Testing Machines, Inc.
Thwing Instrument Co.
Tensile (very light load)
Testing Machines, Inc.
Thwing Instrument Co.
Universal
Testing Machines, Inc.

THERMIONIC RECTIFIERS
General Electric Co.
Westinghouse E. & M. Co.

THERMO-JUNCTIONS (Electric)
General Radio Co.
Rawson Elec. Inst. Co.
Roller-Smith Co.
Wilbin Instrument Co.

THERMO-VOLTMETERS, AMMETERS
General Radio Company
Rawson Elec. Inst. Co.
Roller-Smith Co.
Weston Elec. Inst. Corp.

THERMOMETERS
Bailey Meter Co.
Bristol Company
Brown Instrument Co.
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.
Gas Filled
Foxboro Co.
Taylor Instrument Cos.
Mechanical
Brown Instrument Co.
Foxboro Co.
Mercurial
Bristol Company
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.
Resistance
Brown Instrument Co.
Foxboro Co.
Thwing Instrument Co.
Vapor-Tension
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Wet & Dry Bulb
Bristol Company
Brown Instrument Co.
Foxboro Co.
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.
Thwing Instrument Co.

THERMOSTATS
Bristol Company
Brown Instrument Co.
Foxboro Co.
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.
Wilbin Instrument Co.

THERMOSTATIC BIMETAL
W. M. Chace Valve Co.

TIME METERS
General Electric Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

TIME OPERATION RECORDERS
Bristol Company
Foxboro Co.
J. P. Friez & Sons, Inc.

TIME RECORDERS
Bristol Company
Brown Instrument Co.
Foxboro Co.
Gaertner Scientific Corp.

TIME SWITCHES
General Electric Co.
Westinghouse E. & M. Co.

TIMERS
Rawson Elec. Inst. Co.

TIMING DEVICES
General Electric Co.

TOTALIZING INSTRUMENTS
American Meter Co.
General Electric Co.
Westinghouse E. & M. Co.

TOTALIZING RELAYS
Electric
General Electric Co.

TRAM POINTS
Ford Motor Co.

TRANSFORMATION POINT RECORDERS
Brown Instrument Co.

TRANSFORMERS (Instrument)
General Electric Co.
General Radio Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

TRANSITS
Pocket
Taylor Instrument Cos.

TUNING FORKS—Electrically Driven
Gaertner Scientific Corp.
General Electric Co.
General Radio Co.

TURBIDIMETERS
Bausch & Lomb Opt. Co.

U-TUBE MANOMETERS
Bailey Meter Co.
Brown Instrument Co.
Taylor Instrument Cos.

VACUUM RECORDERS
Bailey Meter Co.
George Sidney Binckley
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.

VACUUM TUBE BRIDGES
General Radio Company

VACUUM TUBE RELAYS

VACUUM TUBE VOLTMETERS
General Electric Co.
General Radio Co.
Rawson Elec. Inst. Co.

VALVES
Automatic Shut-Off
Bristol Company
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Wilbin Instrument Co.
Back Pressure
American Meter Co.
Balanced
Bailey Meter Co.
Brown Instrument Co.
Foxboro Co.
Taylor Instrument Cos.
Blow-off
American Meter Co.
Diaphragm
Bristol Company
Foxboro Co.
Taylor Instrument Cos.
Differential
American Meter Co.
Electrically Operated
Bristol Company
Brown Instrument Co.
J. P. Friez & Sons, Inc.
General Electric Co.
Taylor Instrument Cos.
Wilbin Instrument Co.
Motor Operated
Bristol Co.
J. P. Friez & Sons, Inc.
Wilbin Instrument Co.
Pressure Relief
American Meter Co.
Proportional Air-Gas
American Meter Co.
Reducing
Bailey Meter Co.
Taylor Instrument Cos.
Regulating
American Meter Co.
Bailey Meter Co.
Bristol Co.
Brown Instrument Co.
Foxboro Co.
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.
Wilbin Instrument Co.

VENTURI METERS
Bailey Meter Co.
George Sidney Binckley
Brown Instrument Co.
Foxboro Co.
Pioneer Instrument Co.
Taylor Instrument Cos.

VISCOSIMETERS
George Sidney Binckley
J. P. Friez & Sons, Inc.
Taylor Instrument Cos.

VOLTAGE DIVIDERS
General Radio Co.
Ward Leonard Elec. Co.

VOLT-AMMETERS
General Electric Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.

VOLTMETERS
Electrostatic
General Electric Co.
Rawson Elec. Inst. Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Indicating
General Electric Co.
General Radio Co.
Rawson Elec. Inst. Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.
Recording
Bristol Company
General Electric Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Thermionic Rectifier
General Radio Co.

WATER METERS
Bailey Meter Co.
George Sidney Binckley
Brown Instrument Co.
Foxboro Co.

WATTHOUR METERS
General Electric Co.
Westinghouse E. & M. Co.

WATTMETERS
Indicating
General Electric Co.
Rawson Elec. Inst. Co.
Roller-Smith Co.
Westinghouse E. & M. Co.
Weston Elec. Inst. Corp.
Recording
Bristol Company
General Electric Co.
Roller-Smith Co.
Westinghouse E. & M. Co.

WAVEMETERS
General Radio Co.

X-RAY SPECTROMETERS
Bausch & Lomb Opt. Co.
Gaertner Scientific Corp.

An Improved . . . **CONSTANTAN THERMOCOUPLE WIRE**
Claud S. Gordon Co., Chicago—Cleveland—Indianapolis

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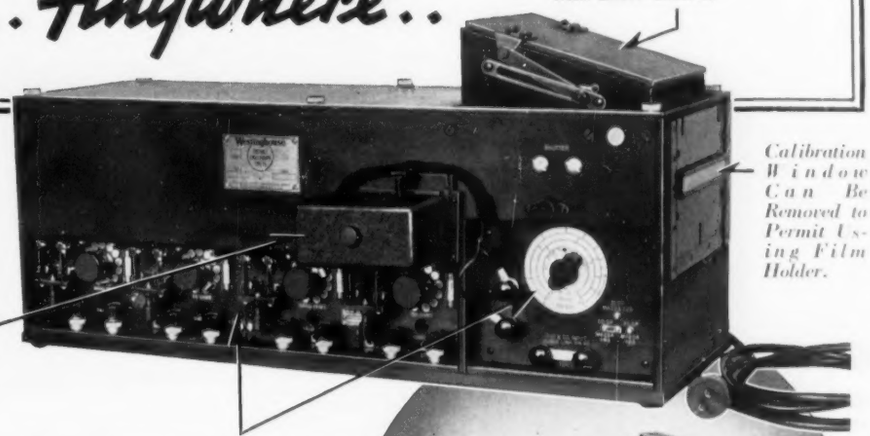
NEW OSCILLOGRAPH ASSURES COMPLETE RECORDS

Anytime .. Anywhere ..

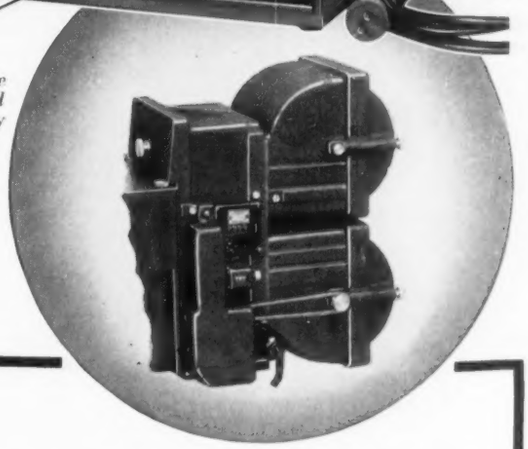


Simultaneous Viewing Screen with Cover Closed.

Calibration Window Can Be Removed to Permit Using Film Holder.

Light Source Uses Automobile Type Lamps . . . Economical and Easy to Obtain.

Various Control Panels That Are Quickly and Easily Interchanged Make Possible the Obtaining of Any Oscillographic Records.



YOU can make complete oscillograms anywhere, at any time with the new Westinghouse PA Universal Oscillograph. And as your oscillography requirements become more complex there is no need to drop the use of the instrument entirely or to purchase a complete new Oscillograph.

You can buy the PA complete . . . or just its main case with only the controls and galvanometers necessary for present requirements. Then, as your requirements change and grow, other controls and galvanometers can be obtained and installed in the original case. Thus, with only a modest initial outlay you can have *an adequate oscillograph available at all times without the purchase of equipment not necessary to your present requirements.*

R 57030

SINCE 1888

METERS INSTRUMENTS RELAYS

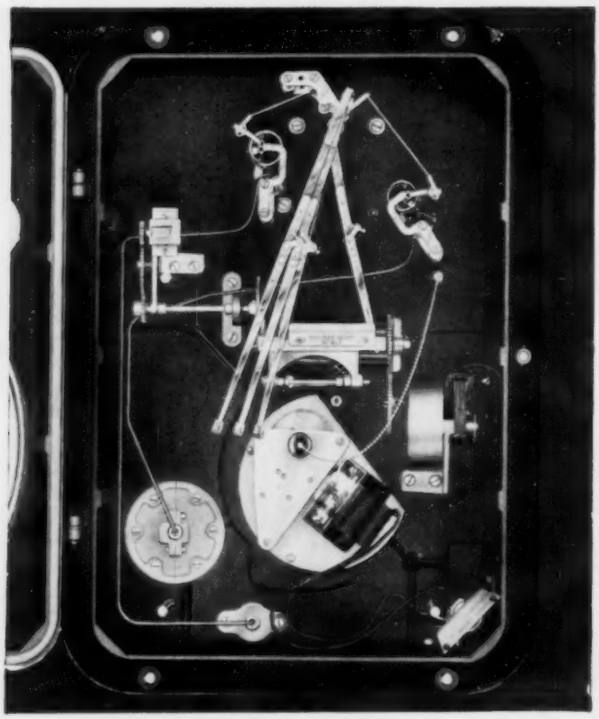
Westinghouse

JUST A FEW OF THE MANY ADVANTAGES OF THE PA UNIVERSAL OSCILLOGRAPH ARE:

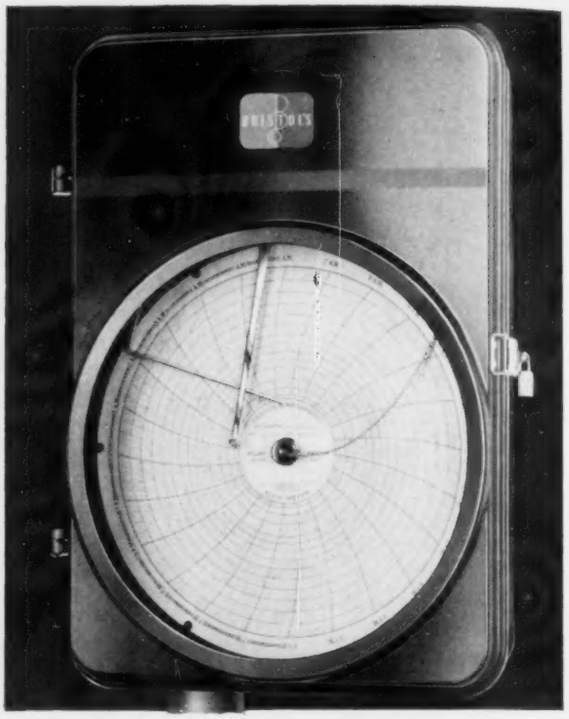
1. SIMULTANEOUS VIEWING—The actual phenomena can be seen on a screen—even while photographing.
2. TWO-HUNDRED FEET OF FILM OR SENSITIZED PAPER can be held in the film holder—cut off for any desired exposure without disturbing supply.
3. REMOVABLE resistance, current, and transformer control panels.
4. INTERCHANGEABLE galvanometers and vibrators.
5. TWIN GALVANOMETERS with external adjustments.
6. SEEPAGE-PROOF galvanometers; *fuse* protection; and automobile-type lamps for light source.
7. WIDE RANGE of film speed assured by a variable-speed, governor-controlled motor.
8. ONE-HALF CYCLE starting time for automatic PA.
9. OPERATES from either 120 volts a-c. or 6-10 volts d-c.
10. ONE TO EIGHT records can be obtained.

BRISTOL'S *New* FLOW METER

for recording, controlling, integrating and indicating flow of steam, gases and liquids



Inside view of Bristol's Integrating Flow Meter, Model 1140 MF, showing integrating mechanism for total flow; and recording systems for rate of flow, pressure and temperature.



Bristol's Flow Meter, Model 1140 M. For panel board or pipe mounting.

Employing the widely accepted orifice and mercury manometer system of flow measurement, this new Bristol's meets the needs of industry for a rugged, accurate and reasonably-priced mechanical flow meter. Even under severe field conditions it can be counted on to give precision measurement.

Meter body is of forged steel, with stainless steel parts inside mercury chambers. Connections are welded or mechanical. The stuffing box is of hardened stainless steel. Grease-packed, it is absolutely leak-tight.

Check valves, operating by gravity, prevent the loss of mercury. A bushing, inserted in the line between the two chambers, dampens the effects of pulsations. Meters for working pressures of 1000 lbs. are tested at 2000 lbs. Special bodies tested at 5000 lbs. are available for working pressures up to 3000 lbs.

IMPORTANT FEATURES! Unique means for checking integrator — Leak-tight stuffing box bearing — Forged steel mercury chambers — Welded joints — Accuracy unaffected by changes in mercury volume.

Write for descriptive Bulletin 425.

THE BRISTOL COMPANY ~ ~ WATERBURY, CONNECTICUT

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BRISTOL'S

TRADE MARK REG. U.S. PAT. OFF.

PIONEERS IN PROCESS CONTROL SINCE 1889